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An input-output econometric model was constructed for the Integrated Computer Aided Manufacturing (ICAM) program of the US Air Force. The model generated is a combined model consisting mainly of classical input-output model, flowgraph theory, and econometric models distinct from input-output models. Major outputs of the model consist of a Transaction Table, and optimal dynamic system models. The optimal dynamic system models consist of a dynamic (multi-period) input-output model and a production system models. A literature review was accomplished to aid in the definition of the context and construction of the overall model and to identify various existing analytical techniques which can be applied within the model. The input-output econometric model as constructed and defined exhibits the flixibility and feasibility necessary for use in an interactive decision support system.

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I. Introduction

The objective of this report is to present the results of an investigation into the feasibility of a Leontief input-output econometric model for manufacturing systems within the framework of a specified hierarchically structured modeling technique known as the ICAM Definition Method (Version 0). One outcome of the research was to illustrate the need for which to define the context within which current structured analysis techniques relates to more general system theories. As such, the report is presented within the framework of multilevel hierarchical system theory with specific reference to the Integrated Computer Aided Manufacturing (ICAM) program of the U.S. Air Force.

The economic model was approached sequentially. Initial efforts were expended on rather straight-forward modeling of classical input-output procedures, followed by augmenting the model with greater complexity. This approach logically led to an extended Leontieff input-output model with quantitative economic/econometric considerations and flow graph capability. The hierarchy of the factory-center-cell-process concept was considered and its relationship to matrix decomposition and aggregation problems that arise. Such problems were research to indicate possible quantitative solution procedures. The model generated was designed in accordance with the specified ($IDEF_0$) design technique and considered within the context of the ICAM Decision Support System (IDSS). The final model developed and presented in this report was termed the IDSS Input-Output Econometric Model.

II. Scope of the Problem

2.1 Context within ICAM Decision Support System

The ICAM program, in its hierarchical (factory-center-cell-process) approach has developed modeling techniques upon which various models have been formulated to explain the functions and information flow occurring within aerospace manufacturing. Within the scope of the current research effort, specific attention is given to function (activity) modeling of a econometric system vis-a-vis with the ICAM Decision Support System under development.

Economic considerations naturally permeate the complete structure of any organization with the levels of an organizational structure typically viewed as a strategic-tactical-operational hierarchy. At each level of an organization, there are different informational needs and specifications to judge or measure any sector or subsector performance. It is also apparent that different types of decision-making occur, and there is a need not only to deal with well-structured problems, but also the unstructured or not-so-well structured problems which occur. To be supportive (by definition), a Decision Support System must have access to the various subsystems that may exist in an organization and integration across information is desired. It should be noted that a Decision Support System views decision-making as a complex activity in which information plays a role, and that design of such a system must be considered within the context of its use.

For an economic model to be feasible within the constructs of an IDSS would require access to the infractructure at various system levels. It would seem logical that the accounting system and/or existing management information system (MIS) of an organization would be one aspect of an IDSS based economic model. Still, consideration must also be given to other problems such as capital budgeting, cost estimating procedures, aggregate planning, inventory systems, make or buy decisions, line balancing and scheduling, capacity planning, and maintenance systems - to name a few. The need to handle less-than-well structured problems and solutions requiring judgment on non-quantifiable factors such as behavioral factors must also be considered.

A proposed economic model, to be aligned with ICAM program intentions, should be generic and have the transferability and adaptability to cross various organizational structures - each with different needs, requirements, and services. Such a capability must be compatible with the decision support system described.

Taking into account the various factors with which IDSS is involved, the current project originally proposed considering the feasibility of a Leontief input-output model as a basis for the development of an IDSS econometric model. The Leontief input-output structure is well documented and has been used in various studies of quantitative interdependence between interrelated economic activities.

2.2 Approach to the Problem

Any approach to the problem of providing a framework for economic decision making in the manufacturing environment would, by definition, have to consider the integrational complexity of the hierarchical structure dominant in the ICAM program. Econometric model development should have the transferrability to be functionally applicable to various manufacturing organizations. Additionally, environmental and policy impact were to be incorporated within the model.

Initially, effort was expended to coordinate with the ICAM program office to obtain information relevant to the effort and to identify contractors, if any, involved in economic model development. Due to the nature of involvement of other contractors with the ICAM program office, information which was thought relevant to the initiation of the current effort was in a lag-time and was unavailable. As such, a different approach then as originally proposed was pursued. This new approach was more general in viewpoint and, in essence, ran parallel to the ICAM program. The effort and scope of the research was broadened to incorporate a much more general literature review, particularly on subjects that were of direct interest. Such an effort, naturally, was dependent on this researcher's conceptualization of the relationship of an econometric model imbedded with the ICAM Decision Support System (IDSS), and drew upon the previous experience and education of this researcher. Thus a general review was pursued with the goal of assessing conceptual developments and research in related fields with the motivation being to tailor the review to specific topics thought to be of current or future benefit to the Air Force.

Specifically, the approach initially consisted of a literature review of multi-level, hierarchical systems, manufacturing systems (with particular emphasis on system descriptions and input-output models), and Leontief models and the relation of input-output models and multi-level systems theory. In addition, emphasis was placed on sector definition and aggregation - two areas which the ICAM program considered important and warranted further research.

As a result of the literature review, it was decided to generate on additional functional model which would serve as a guide for an extended Leontief Input-Output Econometric model. Thesintent of this additional model was to serve to define the strategic/tactical/operational levels of a manufacturing firm and aid in defining the context within which the Econometric model lies.

As mentioned, an extended Leontief Input-Output Econometric model was developed. With the increasing complexity of computer network approaches and the infrastructure of economic/cost accounting/cost benefit/engineering decision models that are prevelant in the literature, it would seem appropriate to relax the constraints of a strictly linear model i.e. Leontief model viewed as a linear activity model. A combined (extended) $IDEF_0$

model having the long-range economic predictability of a classical Leontief input-output model and the flexibility of a graph theoretical model was envisioned and developed. A feedback loop from such an associated flow model to the Leontief input-output model was incorporated.

Thus the approach was to not only consider the partitioning of a Leontief technology matrix into pertinent intersectoral manufacturing activity matrices, but to extend the approach to incorporate flow models. Such flow models were felt to lend themselves more readily to programming implementation. Solution procedures were reviewed which pertained to investigating activity matrix decompositions where each decomposition would essentially define the level in the model (e.g. center level as a function of cell level, etc.).

Although the current effort was to develop an $IDEF_0$ activity model, the underlying thought was to envision the associated information flow. An awareness of the information flow (even though a detailed information flow model was beyond the scope of this project) was felt necessary to justify the feasibility of an input-output approach to the econometric modeling of large scale manufacturing concerns.

2.3 Statement of the Problem

Within the context of the ICAM Decision Support System, the development of a Leontief input-output econometric model compatable to the ICAM program is sought. Such a model would be func- onal and serve to describe the activities of applying an input-output schema to hierarchical large-scale manufacturing systems.

III. Literature Review

This chapter is devoted to a brief literature review of multi-level, hierarchical modeling of systems with particular emphasis on economic modeling of production systems. References are arranged to correspond to the specific section of the report by initial sub-heading and follow the specific subsection. For example, a reference pertaining to activity analysis discussed under section 3.3 would be referenced under the heading of Input-Output and Econometric Systems (section 3.3) and be assigned an appropriate reference number.

It should be noted that the review is not intended to be comprehensive, but rather is tailorea to present the author's own concepts and thoughts on synthesizing existing knowledge toward the objective of developing a hierarchical $IDEF_0$ econometric model for a large scale production system.

3.1 Multi-level Hierarchical System

3.1.1 Multi-level Systems Description

Various investigators (3,6,7,13,15,16,23,24,26) have been quite active during this past decade on multi-level systems theory which resulted from investigation into the general subject area of large scale systems. The text written on the subject matter by Mesarovic et.al (15), was the initial text on the underlying theory. More recent texts have been written by Haimes (7), Dirichx and Jennergren (6), and Saaty (23). The text by Haimes was directed towards research in water resource systems. Of relevance to the current research 15 the recent text by Dirichx and Jennergren (6) with its applications in economics and management.

An excellent survey article by Mahmoud (13) has outlined the general theory of multi-level systems theory, illustrated the basic types of hierarchical structures, and reviewed various contributions to the theoretical and applied literature. Tabak (26) surveyed the applicability of mathematical programming to the solution of multi-level systems optimization and noted at that time (1970) that future research should be directed to improving existing programming algorithms for large scale problems and utilize decomposition techniques whenever possible for problem reduction.

Briefly, three basic multi-level structures have been considered in the study of large scale systems. These hierarchical structures have been identified as (1) multistrata, (2) multilayer, and (3) multiechelon structures which, in general, convey respectively the level of description, the level of decision complexity, and the organizational level. It should be noted that all three types of hierarchies may exist simultaneously in the study of a large-scale complex system, and since each hierarchy serves a different purpose, they may be imbedded within each other. Mesarovic et. al. (15) (from which the following descriptions are obtained) formalized the concepts of the three basic hierarchical systems.

A multistrata system involves vertical decomposition, priority of action, and performance independence. Fundamentally, stratification is descriptive and lower strata explains in more detail how a system functions. The priority of action is termed intervention in hierarchical systems and pertains to the influence of higher levels on lower subsystem levels. Lower level performance, as a response to an intervention, then is viewed as a feedback to the upper level. An effective stratified hierarchical description necessitates that the functioning of the system on any specific level of abstraction be as independent as possible of the functioning of other levels.

The multilayer hierarchical structure, as noted, deals with the complexity of decision making processes. A family of decision problems are defined and an overall solution of the original problem is obtained sequentially by solution of simpler subproblems.

As with the multistrata system, the multilayer system is dependent on two-way communication between level subsystems. This communication link for multilayered systems includes strategy determination, uncertainty reduction by learning methods, and selection of a preferable course of action.

A multiechelon hierarchical structure (also termed a multi-level, multigoal system) is the most general structure and consists of interacting subsystems with some of the subsystems defined as decision-making units and arranged hierarchically. Each subsystem at a given level (echelon) is goal-seeking system with conflicts between subsystems resolved by higher order subsystems. The resolution of conflicts is termed coordination and is accomplished by intervention. Such intervention typically deals with goal-related facts, information, or constraints affecting alternative courses of action. Mahmoud (13) has defined coordination "... as the task of the supremal control systems in which they attempt to cause a harmonious functioning of the infimal control systems by manipulating their interactions, resolving the conflicts, and adjusting the goal and model interventions."

3.1.2 Multi-level Design Techniques

From the viewpoint of the current research effort, the emphasis is on utilizing the Structural Analysis Design Technique (SADT) (1,2) in a defined application area without detailed research on the various concepts and structures within structural analysis and design. Nevertheless, it is believed that an understanding of the context within which current effort lies is of benefit in the manufacturing systems econometric model development initially proposed and that a few brief comments are in order.

Structural analysis and design has within the last decade become an important development in large-scale systems development, and, particularly, in its relation to software development. Software development has led to various modular design techniques such that complex systems can be better understood with the additional benefit of minimizing software costs. It has been stated (4) that:

> "... the added cost of modularity is relatively small compared to the savings gained in software development and maintainability costs ... In addition, structured design is ... an effective means of reducing the cost of systems changes on the total software cost...."

Modular programming, structured programming and the extension of structural programming concepts which are termed composite or structured design naturally evolved from early monolithic program development. Various texts have been written within the past decade on such topics (5,11,18,28,29,30,32).

It has been stated that structured design is a set of general program design considerations and techniques such that software complexity is reduced (25). Thus, such program design techniques are considered compatible, but not equivalent (29), with documentation techniques such as HIPO (11), SADT (1,2), or with coding techniques of structured programming. As defined by Yourdon and Constantine (29),

> "Structured design is the art of designing the components of a system and the interrelationship between those components in the best possible way."

The same authors noted that a structured design approach "... consolidates, formalizes and makes visible design activities and decisions...". DeMarco (5) has defined structured design as a:

> "...design technique that involves hierarchical partitioning of a modular structure in a top-down fashion, with emphasis on reduced coupling and strong cohesion."

Weinberg (28) distinguishes between structural analyses as a top-down graphical approach to all phases of the systems development life cycle whereas structured design is the set of guidelines and techniques used to determine the best way to solve a system's problem by interconnected modules.

3.1.3 The Structural Analysis and Design Technique (SADT)

The Structural Analysis and Design Technique (SADT), proprietary of SofTech Inc., of Waltham, Mass., is a structural decomposition modeling approach characterized by cooperative and coordinated teamwork prior to final model acceptance (1,2,19,20,21,22). As such, models developed by individuals from their own particular viewpoint are considered as working models subject to revision via a feedback approach with other members of the team. A brief review of the terminology and structure of $IDEF_0$ (ICAM definition method-version 0) is given in the subsequent paragraphs.

Structured analysis, specifically $IDEF_0$, uses activity diagrams to describe functions of a system. Such diagrams are composed simply of boxes to represent activities of the system and arrows to represent items processed by the system. An activity is defined as anything that can be named with an active verb phrase and are therefore direct and purposeful. Arrows, labelled with a noun phrase, represent the information (data) or objects needed by or produced by an activity. It should be noted that arrows do not represent flow or sequence, but rather data constraints. That is, an activity is constrained until data is made available to the activity such that the said function can be performed.

Arrows leading into or out of activity boxes are classified either as Inputs, Controls, Outputs, or Mechanisms, (ICOM). The arrows serve to clarify and bound the meaning of an activity box. Briefly, input arrows entering the left side of the box are transformed into output arrows exiting from the right side of the box. Thus, for data input, the activity creates data output. Arrows entering the top of an activity box indicate controls which describe the conditions or circumstances which govern the transformation. Arrows entering or exiting the bottom of an activity box indicate a mechanism on how an activity is carried out. A mechanism may be a person or device.

Overall, every model has a definite purpose and viewpoint within a given context of the model. Questions within the context of the model specify the model, and the purpose and viewpoint determine the orientation of the model. In the $IDEF_0$ methodology every component may be further decomposed into another activity diagram. The model (i.e., hierarchy) dealing with different levels of abstraction is a coherent, consistent structured model composed of boxes and arrows. Various notational designations are used to develop a model. These include node numbers to indicate the position of each activity diagram within a model. ICOM codes are used to indicate the connection between levels of decomposition for a given activity, and tunneled arrows suppress any unnecessary detail. Typically, a nodal diagram stating only the various activities is given separate from the model.

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3.2 Manufacturing Systems

To review, in general, manufacturing systems, or in a larger sense, production systems would be an immense task in itself. Of importance to the current effort is an understanding of what constitutes a manufacturing system, and, in particular, to identify what factors are common (generic) to such systems. As such this effort is concerned not with a comprehensive literature review, but sufficient enough to abstract the necessary minimal structure that properly describes a production and/or a manufacturing system, and using this structure as a basis for the input-output econometric model pursued. The following sections serve to review and describe such systems within the context of a manufacturing firm and to further review input-output models of manufacturing systems.

3.2.1 Manufacturing Systems Descriptions

Various texts and articles have investigated the complexities of large scale manufacturing firms. For the purpose of this research it is necessary to specify a hierarchical manufacturing structure of a firm, the functions at each level and the interaction between levels and the surrounding environment. Publications have dealt not only with overviews of the organization and management of firms (3,8.10,21,23,24,30,31, 42,43), but also more specific topics such as operational planning (2,4,11,19,39,47) and inventory control and scheduling (5, 7,12,18,20,22,34,40). Of particular interest to the ICAM program are computerized and flexible automation systems and software models applicable to manufacturing and production (1,16,17,18,25,27,32,38,41). Group technology concept (15,20, 21,22,36) are playing a more important role in manufacturing systems and are imbedded in the ICAM program.

It has been noted (30) that their are many ways to describe systems management, but similar concepts are used. Four basic processes are descriptive in the system and consist of (1) Planning, (2) Organizing, (3) Control, and (4) Communications. The planning function is involved with the selection of organizational objectives and policies, and the establishment of policies, programs, procedures and methods for obtaining stated organizational objectives and policies. Organizing pertains to the coordination of personnel and resources into a system such that activities performed lead to the accomplishment of system goals. Due to the complexity of large organization systems, the control function is to assure that various subsystems are performing in accordance with generated plans. Communications transfer information among different decision centers within an organization, and would in many cases would be embodied in the concept of management information systems.

From a hierarchical viewpoint, strategic, tactical, and operation levels are typically defined. As such, the planning function as mentioned would be, by definition, strategic planning. In a hierarchical breakdown, strategic planning would deal with decision making involving goal determination and large-scale resource allocation. Such planning would constrain and guide management at the lower tactical and operational levels. The organizing function would consist of the tactical and operational (detail) planning. With guidelines provided from the strategic level, the tactical level determines how to allocate available resources to projects, and in turn, guide and constrain detail (operational) planning.

Various authors have developed schematics to illustrate the relationships among a manufacturing firm's components. Some are quite complex and complete detail of the multitude of production systems description are outside the scope of this research. A few of the more recent descriptions pertaining to production systems are worth mentioning due to the impact they had on the extended input-output model that was developed and which is presented in the next chapter.

It has been illustrated by Hitomi (22) that a management system for manufacturing can be viewed both hierarchically and functionally. A typical pyramidal representation is given in Figure 3.1. The hierarchical division as shown is identical to the strategic (administrative), tactical (management), and operational levels already discussed. Four basic functions identified as important in this particular schematic are the production function, the marketing (sales) function, the personnel function, and the finance function. The production

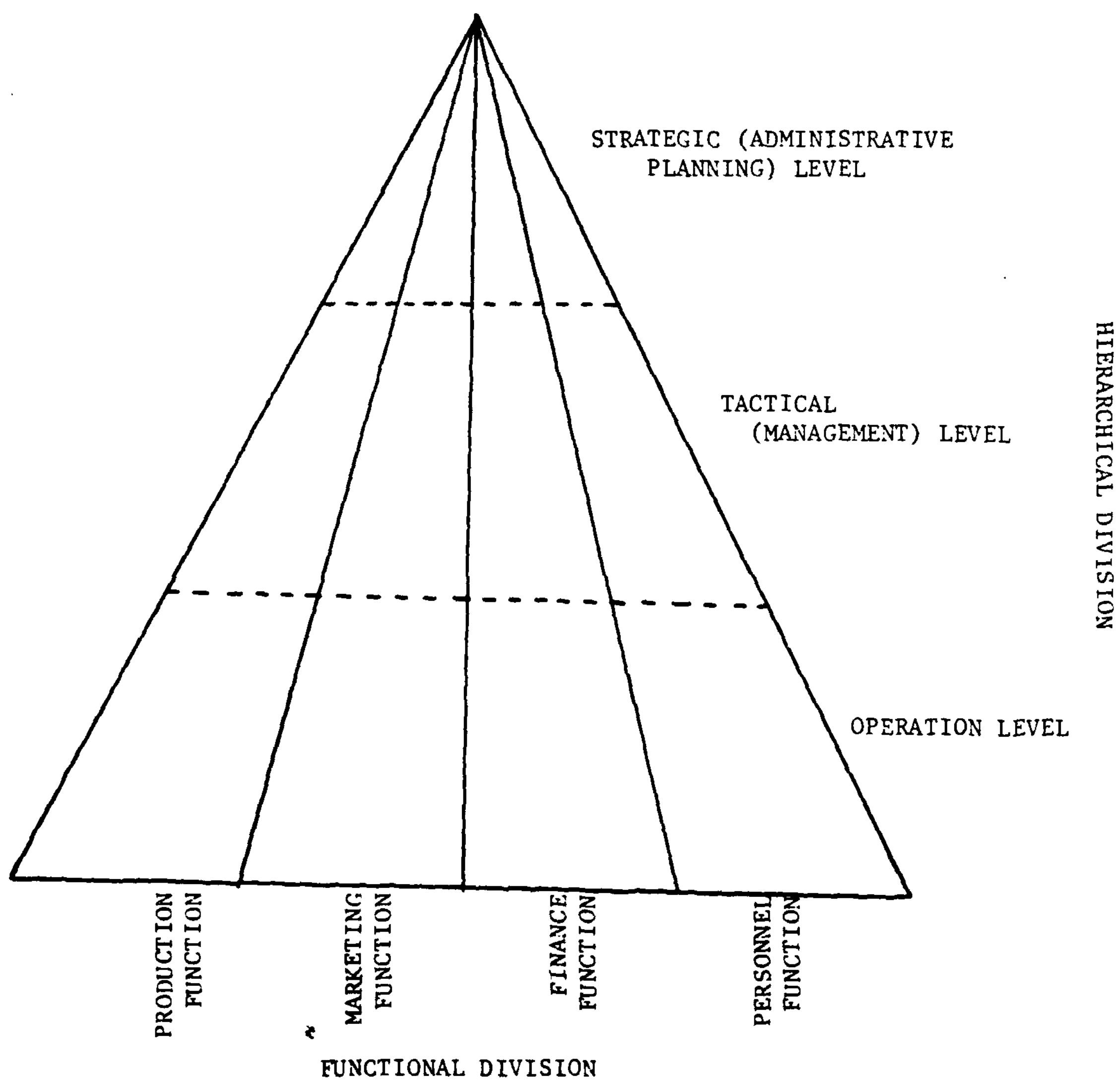

Fig. 3.1 A Management system can be viewed from two aspects: hierarchical and functional structures (from ref. 22)

function is the most important function in a manufacturing firm and is concerned with the material flow: the conversion of factors of production into finished products which are marketed. This material flow system corresponds to the operational level of the hierarchy, and in addition to inventory, comprises a chain of procurement, manufacture and sales (each of which can be considered as subsystems to the logistics system).

The main functions mentioned are not to be thought of as the only functions or as completely independent subsystem. Riggs (40) lists six major policy and administrative functions of a large organization. (Personnel, product development, marketing, finance and accounting, purchasing, manufacturing) each of which has operational subsections within each basic functions. Such multiple subsection divisions were noted by Riggs to "... help in defining responsibilities but they increase the dangers of conflicts from overlapping areas of influence ..." In addition, Riggs defined a management information system (MIS) as any structure that provides managers the needed information to conduct operations. Such a structure can be simply pencil-based, or as has been commonly accepted, computer-based. The type of MIS function and degree of applicability by organizational level and nature of responsibility is presented in Table 3.1. The hierarchical levels of an organization given in Table 3.1 have been further decomposed to reflect the operational level lower management supervision over production workers. At the lowest level of the hierarchy

TABLE 3.1 Hierarchical Levels of an Organization and the Impact of Information (adapted from ref. 40)

Organizational Level	Nature of Responsibility	Information Utilization	Information Transfer	Information Processing	Information Retrieval
Senior Management	Unstructured Decision Making	M	M	L	L
Middle Management	Structured Decision Making	H	H	M	M
Lower Management	Production Supervision	L	L	H	L
Production Workers	Output of Products	H	M	M	H
Office Workers	Data Transactions	M	M	H	L

Degree of Applicability

L: Low M: Medium H: High

Information Utilization = Data applied to activity management

Information Transfer = Moving data reliably and rapidly

Information Processing = Capturing and storing appropriate data

Information Retrieval = Ready access to timely data

data transactions are carried out. The actual product production level would (in an ideal setting) have high information utilization and retrieval characteristics.

Perhaps the most comprehensive text on MIS which has been beneficial to the current research effort is the 1975 text by Thierault (45). A large portion of the text is devoted to a hierarchy of subsystems for a typical manufacturing firm. From the hierarchical viewpoint each of the firms major functions generates information to assist other subsystems. Organizational objectives are implied in major subsystem activities and complement each other. The eleven major functions presented consist of corporate planning, marketing, research and development, engineering, manufacturing, inventory/purchasing, physical distribution, finance, accounting, and personnel. One example given for the accounting function exhibits the decomposition of the major accounting subsystem into intermediate subsystems (budgets, inventory control, cost control, accounts payable/ receivable, customer biller). Further examples are given on the finance, inventory, purchasing, corporate planning, etc., major subsystems. Of considerable interest was the modular systems concept employed in the decomposition of the major subsystems. As noted by Thierault, the modular systems concept identifies separate but detailed information modules. Major modules such as finance can be subdivided into intermediate modules (e.g. cash management, capital budgeting, source of funds) and further into minor modules and basic modules. As noted previously (section 3.1.2), modular design techniques are beneficial in minimizing software costs and are more easily maintained.

To be an operational decision support system the subsystems must be integrated to operate in a real-time mode and function as a unified system. Such integrated subsystems provide a comprehensive information and control system that integrate all related data and functions of concern to individual managers, desiners, etc. A individual manager's operation (subsystem) then has the capability to access and mesh with related subsystems and to take advantage of processing already accomplished by such other related subsystems.

To accommodate decision-making along functional lines, the data base must be oriented along functional, rather than departmental lines. As noted by Thierault (25), the data base can be structured horizontally, vertically, or combined in a horizontal/vertical structure. He notes that the latter approach is the best and that:

> "...The combined approach integrates the data base for all management levels and allows retrieval of information on the same level. It is a decision-oriented data base ... the business operations structure of each level is equated horizontally and vertically with the data base which, in turn, is equated again in both directions with the information structure. In three dimensions, a matrix could be formed in which the plane of each structure level would intersect with each of the other levels...."

With such a system, the data base relates business operations levels to information system levels.

For each of the eleven major subsystems considered, Thierault devotes a chapter with the expressed purpose of tieing together the subsystems in a real-time MIS environment. The eleven chapters are based on the operation of a hypothetical medium size manufacturing firm making products for the consumer.

To adequately describe a manufacturing system within the context of an organizational firm, two other primary references sources (texts) were used. These texts consisted of the work of Halevi (18) and of the previously mentioned text by Hitomi (22). To define manufacturing systems, the latter text distinguishes between the structural, transformation, and procedural aspects of manufacturing systems. A structural manufacturing system is a static definition of the system and consists of a unified assemblage of hardware and workers supported by production information. This structural system:

> "...performs on production objects (raw materials) to generate useful products ... creating utilities to meet market demands...(and)...forms a static spatial structure (layout) of a plant...(which)... influences the effectiveness of the transformation process in production; hence, the optimum design of the layout is the problem of the structural aspect of the manufacturing system."

The transformational (functional) definition defines a manufacturing system:

> "...as the conversion process of factors of production, especially raw materials, into finished products, aiming at a maximum productivity and efficiency. This system is the material flow and is called the production process system..."

Viewed as a "material flow," a manufacturing system consists of an acquisition stage, a factory conversion state, and a distribution stage. In essence; this is a production logistics system which consists of a material supply system, a material-handling system, and a physical distribution system.

Closely associated with the production process system at the operational (shop-floor) level would be various activities which would be associated with the operation (tactical) planning. Table 3.2 has been constructed to illustrate the hierarchical levels (denoted by major systems) and the various sybsystems and functions which are performed. This table (in conjunction with other primary references) served as the basis to define the strategic/tactical/operational levels of a manufacturing firm which in turn aided in the development of the extended Leontief Input-Output Econometric model.

The operation (tactical) planning and the administrative (strategic) planning constitute the procedural definition of a manufacturing system i.e., the manufacturing system is considered as the operating procedure of production which is the management system of production.

Thus, a production/manufacturing system is a unified or integrated approach of the production process system (material flow) and the production management system (information flow). In a strict or classical sense a manufacturing system consists of the logistic system and is shop-floor (operational level) oriented. With the advent of computer integration onto the shop-floor it has become possible to incorporate the information

Table 3.2 Systems and Subsystems for an Integrated Production Management System (adapted from ref. 22)

System	Subsystems	Function	Comments
Administrative[1] Planning		Establish objectives and policies and supervise planning, implementation and control in tactical and operation levels	Long planning horizon
	Strategic Long Range Planning		Cost-benefit analysis typical
	Tactical Feasible Programming		To direct strategic plans to lower levels
Operation[2] Planning		Establish implementation procedures for logistic system	
	Forecasting	Provide accurate forecasts	
	Aggregate Production Planning	Material Planning Facilities Planning Manpower Planning Process Planning and Scheduling Inventory Planning	a) Detailed feasible plan for operations by functio b) Resource planning = materials, facilities and manpower planning
	Sales Planning	Plan future marketing and sales	Dependent on forecasting subsystem
	Product Planning	Design competitive products	
Operational[2] Control		Auditing of Progress and monitering of deviation of performance from planned standards	
	Purchasing Control Production Control Quality Control Sales Control Inventory Control	Control of flow of raw materials to finished products	
	Personnel Control Facilities Control	Control of resources of man, machines, and money	

Table 3.2 (continued)

System	Subsystem	Function	Comments
Logistic(3)		Implementation of Production Planning	Detailed planning and scheduling implemented
	Procurement	Acquire production resources	
	Manufacturing	Produce finished product via conversion, transfer, storage activities	Producer produces as required by sales in relation to finished product inventory
	Sales		
	Inventory	Raw materials inventory Work-in-process inventory Finished product inventory	Inventory subsystem acts as buffer to smooth material flow
Service	Information	Provide accurate information	Information provided at various decision points in total system at right time
	Research and Development	Develop new products	
	Technology	Use professional knowledge	Staff activity
Supporting	Personnel Facilities Finance	Acquire necessary skills Procure production facilities Acquire and use capital funds for business activities	

(1) Strategic Level (2) Tactical (Management Level (3) Operational Level

flow as part of a real-time environment responsive manufacturing system.

Associated with each activity in a manufacturing firm would be a cost structure. Cost structures would have to be considered in any economic model. Such cost structures would by definition be associated with the total integrated manufacturing system i.e., the combined material flow-information flow (production process system-management system).

3.2.2 Input-Output Models of Manufacturing Systems

In its most basic terms, an input-output model corresponding to the description of a manufacturing system given in the previous chapter would have (if we are concerned only with material flow within a factory) three basic activities (22). These activities would consist of (1) conversion: converting the form of a material by performing operational activities, (2) transportation: actual materials handling where in-process materials are moved either physically or automatically via transfer mechanisms, conveyors, robots, etc., and (3) storage: a delay with no change of form or place occurring and classified as either raw-materials inventory, work-in-process inventory, or finished product inventory.

The conversion activity would include all manufacturing operations including casting, forging, metal-forming, pressing, joining, material removal, treatment, assembly, etc. in addition to supplementary operations such as inspection, quality control,

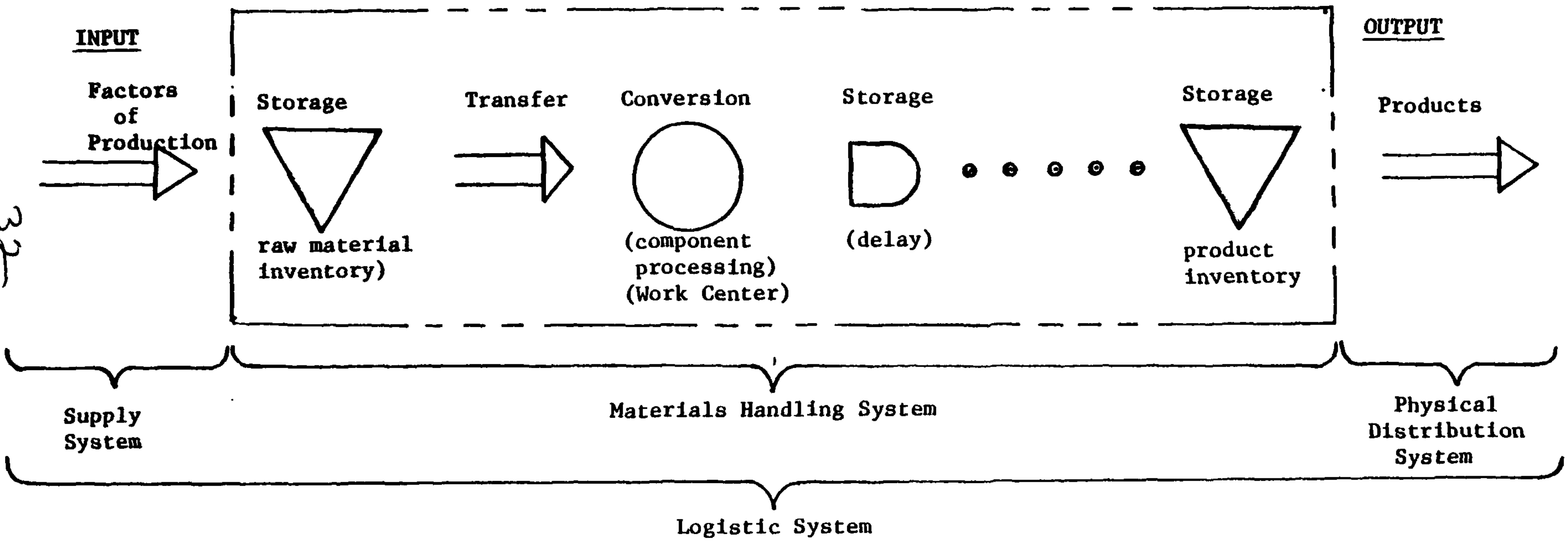

Figure 3.2 Schematic of Input-Output Logistic Model of Multistage Manufacturing System (adapted from references 22, 36, 40, and 41)

32

packaging, etc. A schematic of an input-output model of a multi-stage system from a material flow viewpoint is given in Figure 3.2.

In its basic form as depicted in Figure 3.2, a multi-stage manufacturing system model would have inputs consisting of factors of production e.g. manpower, resources, etc. For a material flow model, the input would simply be raw materials acquired through a supply system, a materials handling system within which raw materials would be manufactured into products (output) having utility, and a physical distribution system.

Two additional points are worth mentioning because of their impact on the ICAM program, namely, 1) Group Technology and 2) Materials Requirement Planning. The concept of group technology is applicable primarily at the operational level due to its effect on plant layout and process flow (15,22) and on the tactical level because of the production scheduling and control considerations (20,22,37). Material Requirements Planning (MRP) is a technique used in many aerospace industries and is incorperated into the ICAM program.

MRP is a method for coordinating detailed production plans in multi-stage production systems (31,35). The concept of MRP is to begin with a master production schedule and work backwards to determine when and how much of each component will be needed in the manufacture of a product. Because requirements are determined from the master schedule defining the end product, the requirements are said to have dependent demand. Under an

MRP system, the plans and schedules are under control and are known. Thus, the demand is dependent on the plans and schedules. With such a system, the demand can be accurately anticipated in both the amount and in the timing. In forming a master schedule to drive a MRP system, the information system must collect all required information inputs. Typical sources of information include forecasts, orders (both customer and inter-company), and service parts and safety stock requirements. For an MRP system to be used effectively, a complete and accurate bill of materials is needed. Two types of MRP systems are recognized 1) Regenerative system: the production plan is updated at regular intervals and 2) Net-change system: each change that occurs is posted immediately and exploded through the system.

Inventory control methods are applicable to situations with independent demand. As such, they apply when many small orders are arriving at random times for each item. It has been noted (31) that it is a significant error to apply inventory control methods to items having dependent demand.

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3.3 Input-Output and Econometric Models

A directed review was accomplished to determine the applicability of an input-output economic model and analytical techniques at the Strategic, tactical, and operation levels. Particular emphasis was placed on determining the applicability of a input-output econometric model as originally proposed, and if necessary, to determine extensions or modifications that were more applicable.

As a reference starting point, various models used in forecasting have been summarized in Table 3.3. The table has been adapted from the work of Chambers, et. al. (7) and serves as a comparison of not only input-output and econometric models, but also of short-range techniques having applicability at the operational level.

The column labeled accuracy in Table 3.3 pertains to the accuracy of a technique employed over a short (0 to 3 months, medium) (3 months to 2 years), or long (2 years or more) period of time. These time periods were taken as corresponding to the operational, tactical, and strategic levels, respectively. As can be noted from the table, a economic input-output model has very good accuracy for mid-term and long-term periods. Such a model is a combination of econometric models (a system of interdependent regression equations used to describe some sector of economic sales or profit activity) and of a classical input-output model. The disadvantages are the relative costs and the time required to develop a data base for reliable and accurate decision making. In addition, as has been summarized in Table 3.4, such a combin-

Table 3.3 Comparison of Forecasting Techniques[1]
(adapted from ref. 7)

Forecasting Technique	Accuracy[2] S	M	L	Applications	Relative Cost[3]	Time Required to develop forecast	Data Requirements
Input-Output Model	NA	G-VG	G~VG	Forecasting of company and division sales for industrial sectors and subsectors	\$50,000 +	6 months +	~10 years history; product and service flows within a corporation
Economic Input-Output Model	NA	G~VG	G~E	Forecasts of company sales for industrial sectors ans subsectors	\$100,000	6 months +	Minimum of 3 years history to start
Econometric Model	G-VG	VG~E	G	Forecast of sales by product classes, forecasts of margins	\$5,000 + [4]	2 months +	Sufficient quarterly history (several years) to obtain good relationships; observations > number of independent variables
Life-cycle Analysis	P	P~G	P~G	Forecast of new product sales	\$1,500[4]	1 month +	Market survey results; annual sales of product being considered
Regression	G~VG	G~VG	P	Same as Econometric Model	\$100[4]	Dependent on ability to identify relationships	Same as Econometric Model
Moving Average	P~G	P	VP	Inventory Control (low value items)	\$.005[4]	1 day	Minimum of two years history; moving average must be specified
Exponential Smoothing	F~VG	P~G	VP	Production and Inventory control; forecasts of margins and other financial data	\$.005[4]	1 day	Same as moving average
Box-Jenkins	VG~E	P~G	VP	Production and Inventory control (large volume items); forecasts of cash balances	\$10.00[4]	1-2 days	Same as moving average; more history advantageous for modern identification

(1): Table to be used as general guidelines only. All variations of a technique not described. Table is descriptive of basic concept only
(2): S-Short term (0~3 months); M-Medium term (3 months~2 years); L-Long term (2 years or more).
(3): Estimates of costs approximate. Reader should note that reference to techniques dated in 1960's.
(4): Reference states that calculation is possible without a computer.

ed model is not application for short-term decision making.

Ideally, it would be reasonable to assume that an IDSS system should have long-term stability, and also be augmented for more adaptability, flexibility and short-term decision making capability. A comparison of the techniques presented in Table 3.4 indicates that short-term decision making can be accomplished with time series analysis and projection techniques e.g. moving average, exponential smoothing, Box-Jenkins.

Of the techniques listed, the Box Jenkings Technique is optimal in that it assigns small errors to the data history than any other model. Still, from the viewpoint of the IDSS program within ICAM, a literature search was done to identify a time series approach that was more amenable to modeling techniques within the ICAM, a literature search was done to identify a time series approach that was more amenable to the modeling techniques with the ICAM Program. The time series technique which suggested as a possible viable, technique is a combination of time series and systems modeling (36).

The following sections consists of a review of classical input-output analysis, activity analysis, problems relating to sector definition and aggregation, and systems engineering approaches (graphical analysis). It was the intent of this reseacher to arrive at a description of a model which would aid in the resolution of the economic description within IDSS. In addition, solution procedures (analytical techniques) thought relevant to an IDSS economic model are reviewed.

3.3.1 Leontief Models and Econometric Considerations

A Leontief model is an input-output model which represents a complete economic system. It is an adaptation of the theory of general equilibrium to arrive at an empirical approach to study quantitative interdependence between interelated economic activities. A matrix representation of a Leontief model shows the flow of production of each major section of an economy and the consumer of that production. As such, a complete industry rather than an individual firm is the unit of production (18, 28,29,30).

A Leontief input-output can be considered as a substochastic (open) or stochastic (closed) model. The open or closed concept refers to the way flow (typically dollars are considered as homogenous flow-units) to the rest of the "world" is handled. A substochastic model can be expanded to a stochastic model by adding sectors to account for flow to the rest of the "world." Typically, a substochastic model consists of n sectors which carry out transactions among themselves and the rest of the "world". Input-output analysis as developed by Leontief in the 1930's focuses on the interrelationships between sectors of the economy (11,29,30) and has seen considerable application (8,19,25,35,37,40).

To do an input-output study, three main tables must be produced: (a) A transaction table, (b) A table of technical coefficients (35). The transactions table, which serves as the statistical basis of the input-output system is the basic table of an input-output system. The various economic flows are entered in the table in quantitative terms. A schematic layout is given in Figure 3.3.

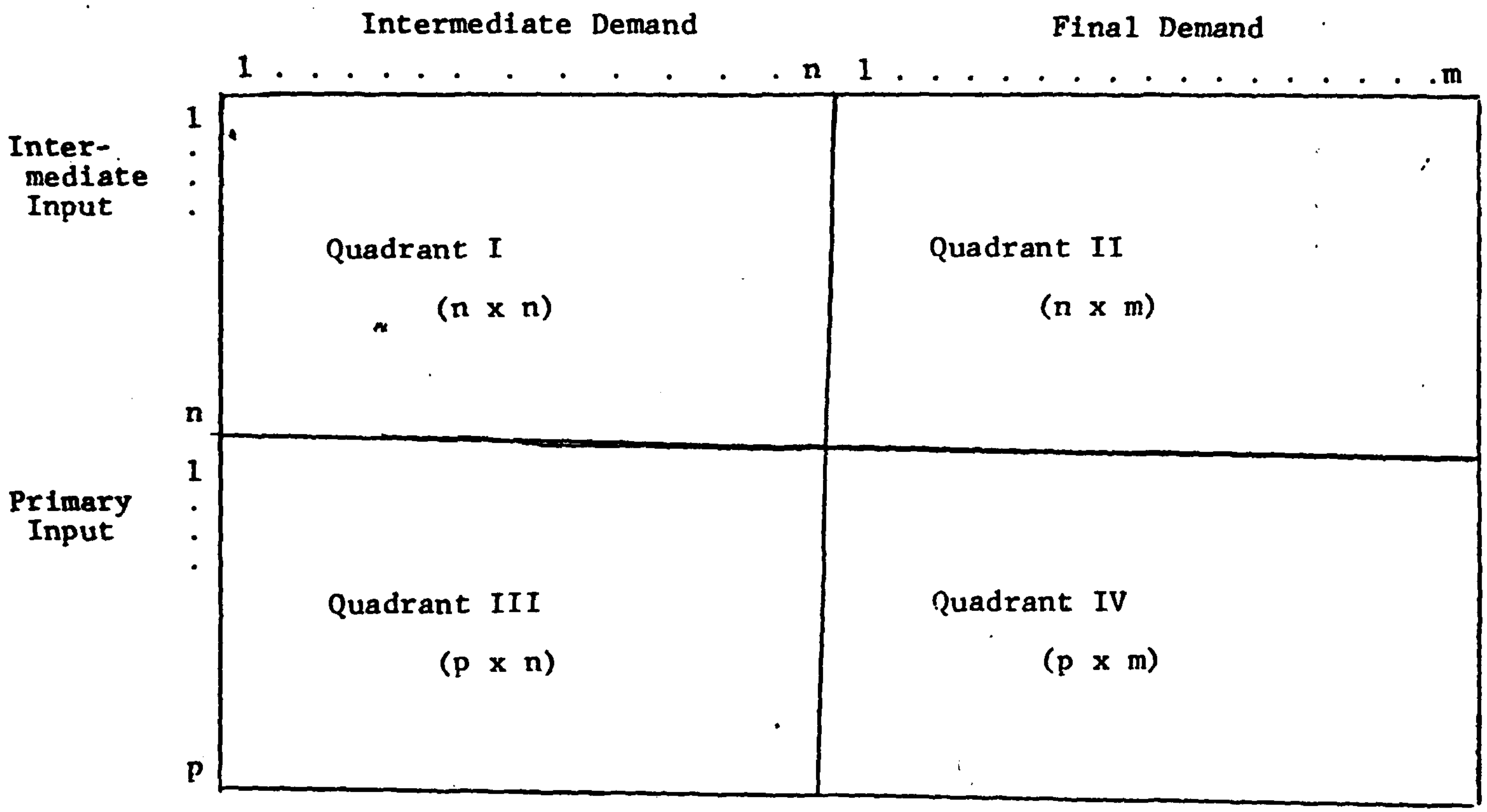

Figure 3.3 Schematic Layout of a Transaction Table Used in Input-Output Analysis

The table consists of four quadrants (I,II,III,IV) arranged as shown in Figure 3.3. The left-hand side (Quadrants I and II) represents the inputs to production processes of productive sectors whereas the right-hand side (Quadrants II and IV) represents sales to final disposal sectors, or more accurately, inputs are labeled vertically (column) along the left-hand side and outputs are labeled horizontally (row) across the top. Inputs are divided into n intermediate inputs and p primary inputs where inputs typically consist of economic sectors.

Intermediate output to intermediate demand represents quadrant I and shows the flows of goods and services which are both produced and consumed in the process of current production. This flow is typically termed inter-industry flow or intermediate demand. As such, quadrant I is an nxn matrix having the same sector definitions vertically and horizontally. Quadrant II indicates the various (m) elements of final demand for each of the n producing sectors.

Primary inputs to the productive sectors make up quadrant III and form a p x n matrix. The inputs are described as primary since they are not part of the output of current production which is defined by the rows forming quadrants I and II. Primary inputs typically consist of imports, indirect taxes, wages, salaries, deciation, etc. Common usage is such that primary inputs referring to land, labor, and capital are termed factors of production, although as pointed out by O'Connor and Henry (35), such terminology should not be used to avoid confusion. The fourth quadrant (IV) completes the transaction table and consists of primary inputs to final demand.

In an input-output table, the overall row total across quadrants I and II is always equal to the overall column total vertically down quadrants I and III. i.e., the total value of output of each productive sector equals the total expenditures on inputs for that sector. This equality is not imposed on the primary input sectors or on the final demand sectors, but the sum of all the final sectors should be equal to the total of primary inputs. Such equality of inputs and outputs is an accounting procedure of the flows in a transaction table.

Following the construction of a transaction table, the next table produced is a table of technical coefficients or what is termed the table of unit cost structure. The tables are obtained by dividing every item in quadrants I and III by the total of the column in which the item is recorded. What these operations amount to is to normalize the data. The contribution of the various inter-industry flows and primary inputs can then be expressed as a fraction contribution absorbed by each inter-industry output.

As stated previously, one of the main aims of input-output analysis is to study changes that arrive between different sectors. For example, a change in final demand for one sector causes ramifications throughout the system. To study such interdependencies, total or interdependent coefficients are used. Table 3.4 serves to illustrate the formulation of such coefficients. For mathematical simplicity, intermediate and primary inputs are combined i.e., Quadrants I and III are combined into an (n+p) x n = n'xn matrix. In addition, Quadrants II and IV are combined into an (n+p) x m = n'xm matrix and only total final demand is considered (summed over m for each i = n'). Briefly, the internal flows are represented by x_{ij}, where i represents the row and j the column as shown in Table 3.4. The total outputs of the interindustry sectors are represented by X_i whereas the final demands for these sectors are represented by Y_i. Note that total inputs are represented by X_j and are given at the bottom of the table. As discussed previously, there is an equality of inputs and outputs.

The total coefficients are formed from the technical coefficients. If we represent the technical coefficients as a_{ij} where

$$a_{ij} = \frac{X_{ij}}{X_j}$$

and note that the various flows in Table 3.4 can be represented by a system of linear equations as follows:

$$\begin{array}{l} X_1 = x_{11} + x_{12} + \dots + x_{1n} + Y_1 \\ \vdots \\ X_{n'} = x_{n'1} + x_{n'2} + \dots x_{n'n} + Y_{n'} \end{array}$$

Then simple substitution gives the following system of equations:

$$\begin{array}{l} X_1 = a_{11} X_1 + a_{12} X_2 + \dots + a_{1n} X_n + Y_1 \\ \vdots \\ X_{n'} = a_{n'1} X_1 + a_{n'2} X_2 + \dots + a_{n'n} X_n + Y_{n'} \end{array}$$

The system of equations as can be rewritten as

Table 3.4 Illustration of Flows in Symbolic Terms

All Inputs	Intermediate Demand 1 2 ... j ... n	Total Final Demand	Total Output
1	x_{11} x_{12} ... x_{1n}	Y_1	X_1
2	x_{21} x_{22} ... x_{2n}	Y_2	X_2
⋮	⋮ ⋮ ⋮	⋮	⋮
i	x_{ij}		
⋮	⋮ ⋮	⋮	⋮
n'	$x_{n'1}$ $x_{n'2}$ ... $x_{n'n}$	$Y_{n'}$	$X_{n'}$
Total Inputs	X_1 X_2 ... X_n		

X_i = total output of interindustry sector i

Y_i = *final demand of interindustry sector i*

x_{ij} = interindustry flow between sectors i and j

$$X_i = \sum_j x_{ij} + Y_i \quad (i = 1,\ldots,n')$$

NOTE: For table as shown, intermediate inputs and primary inputs have been combined into all inputs.

$$(1-a_{11})\, X_1 - a_{12}\, X_2 - \cdots - a_{1n}\, X_n = Y_1$$
$$\vdots$$
$$-a_{n'1}\, X_1 - a_{n'2}\, X_2 - \cdots - (1-a_{n'n})\, X_n = Y_{n'}$$

or in matrix form

$$\begin{pmatrix} (1-a_{11}), & -a_2, & \cdots, & -a_{1n} \\ \vdots & & & \\ -a_{n'1}, & \cdots, & & -(1-a_{n'n}) \end{pmatrix} \begin{pmatrix} X_1 \\ \vdots \\ X_n \end{pmatrix} = \begin{pmatrix} Y_1 \\ \vdots \\ Y_{n'} \end{pmatrix}$$

which can be represented as

$$(\tilde{I} - \tilde{A})\, \tilde{X} = \tilde{Y}$$

where $\tilde{I}$ is the identity matrix, $\tilde{A}$ the matrix of technical coefficients, $\tilde{X}$ the vector of outputs, and $\tilde{Y}$ the vector of final demand.

In input-output analysis, the $\tilde{Y}$ is assumed as exogenous or given such that the problem is to determine $\tilde{X}$, the vector of outputs. Simply stated this means to determine the inverse of $(\tilde{I}-\tilde{A})$ i.e.

$$\tilde{X} = (\tilde{I}-\tilde{A})^{-1}\, \tilde{Y}$$

The numerical value for the elements of the inverse $(\tilde{I}-\tilde{A})^{-1}$ matrix are the interdependence (total) coefficients.

The previous expression for the technical coefficient, a_{ij} was given as

$$x_{ij} = a_{ij}\, X_j$$

where x_{ij} can be interpreted as the output of industry (sector) i required to produce a unit of good $_j$ in dollars. Typically, X_j is considered as the output of only the interindustry sectors. The technical coefficient, or more aptly, the coefficient of production, a_{ij}, related the amount of goods i required for production of one unit of goods, $_j$.

For the primary inputs (resources) of the input-output table, the Leontief approach assumes

$$h_{kj} = e_{kj} X$$

where h_{kj} is the amount of primary input (resource) k required to produce a unit of goods $_j$. The coefficient of production relating amount of resource k required for the production of one unit of goods, $_j$, is e_{kj}.

The input-output modeling approach requires that the production function be represented by a particular form (21,39). The production function which relates the inputs to the outputs and which governs the total output of activity X_j can be expressed in general form as the following function:

$$X_j = f\ (X_1,\ X_2,\ \ldots\ X_n;\ h_1,\ \ldots\ h_p)$$

where h_k (k = 1, ... p) are the p resource (primary) inputs and $X_1, \ldots, X_n$ are interindustry inputs.

With the assumption that all sectors are minimizing their required input (i.e., general equilibrium analysis), the above expression can be written as the input-output production function

$$X_j = \min\ \left(\frac{x_{ij}}{a_{1j}}, \ \ldots\ , \frac{x_{nj}}{a_{nj}}; \frac{h_{1j}}{e_{1j}}, \ \ldots\ , \frac{h_{pj}}{e_{pj}} \right.$$

Production functions and their formulation have received a considerable amount of attention and have been basic in the theory of the study of the firm. The input-output production function is a limiting case of one of the most widely used production functions in empirical work, the constant elasticity of substitution (CES) production function. Using Intrilligator's (24) notation, the CES function for single output and two inputs is given as

$$y - A\ \delta L^{-\beta} + (1-\delta)\ K^{-\beta\ -1/\beta}$$

where y is the output, L is the labor input, and k the capital input. The parameters $A(>0)$, $\delta(0<\delta<1)$, and β (≥ -1) defining this production function are the scale parameter, the distribution parameter, and the substitution parameter, respectively. The CES function is a family production functions which include as special cases the Cobb-Douglas, input-output, and linear production functions. The limit of the CES as $\beta \to \infty$ for the above expression results in input-output production function for the two input, single output case. For further information on production functions, cost functions and their application to the theory of the firm, the reader is referred to the text by Intrilligator (24), particularly chapter eight.

The application of linear programming to aggregate production planning and production analysis encompasses the field referred to as activity analysis (4). Whereas input-output models are characterized by a single activity (method) for producing each output and a single output for each activity, the more general activity analysis of production can consider joint inputs for an activity, substitution between inputs for many activities, joint outputs for individual activities, and substitution between outputs for alternative activities with the same outputs (27). Haimes (21) given an input-output model formulated as a linear programming model in which the equilibrium solution to a Leontief economy can be obtained by solving the linear program.

It has been noted that the Leontief model has appeared in a number of forms. Of considerable interest has been a dynamic model. Dynamic input-output models have been of interest to the US Air Force since at least 1952 (22).

Baumol (4) has noted that two basic requirements exist for a dynamic Leontief system. These dynamic conditions are: 1) the current output of each sector must be enough to meet consumptive demands plus interindustry demands plus demand for addition to inventory, 2) capital stock must be at a minimal level so as to produce planned output levels for a current period under consideration.

A disadvantage of input-output analysis is that the tables are out of date by the time they are constructed, and an approach to update the coefficients in the tables is preferred. To update interindustry structures, many possible methods have been used. These methods include least-squares, time-series, and the RAS method as proposed by Stone and his associates (35).

From the viewpoint of the ICAM program, and particularly the development of an economic model for IDSS, it was considered important by this researcher to extend the input-output model such that analytical techniques felt important for a generic model were identified and could be incorporated into the $IDEF_0$ model structure as mechanisms e.g., RAS method, time series analysis, etc...

Such extensions should include not only econometric capability and input-output models where the coefficients are random variables but also a viable approach to sector definition and disaggregation. To be congruent with the approach of this report, systems engineering approaches should also be included. This latter topic is covered in the next section. It should be noted that the analytic techniques mentioned in subsequent paragraphs are not reviewed in depth and that it is not the intent of this report to state that such techniques are the only available techniques. The viewpoint taken was to consider the needs of IDSS and to attempt to identify a functional structure of a extended input-output model to satisfy such needs.

One such extension is the existence of a large amount of econometric models. As noted by Intrilligator (12,24), econometric techniques are simply extensions of statistical techniques. These techniques are primarily from regression theory with least squares techniques being predominant. Intrilligator (24) notes that the general econometric model is an algebraic, linear (in parameters) stochastic model with jointly dependent endogenous variables and exogenous or lagged endogenous variables. The models can be either static or dynamic. Structural analysis, forecasting, and policy evaluation are three principal purposes of econometrics. Structural analysis is an investigation of underlying interrelationships of the system under consideration and the interpretation of specific coefficients or combinations of coefficients. It can be used to test rival theories (e.g. Cobb-Douglas versus input-output production functions).

The second major objective of econometrics is forecasting i.e. prediction outside the available sample of data. Forecasting in itself is closely related to policy evaluation which is the use of estimated models to choose between alternative policies.

From the viewpoint of the current effort, it would be advantageous to combine input-output models with econometric techniques. For a viable IDSS, dynamic models should be the norm (both linear and nonlinear) and stochastic capability should be available.

Due to the user orientation of the projected IDSS, accommodation of activities related to the construction of graph theoretic models would also be advantageous. Such graph theoretic models could then serve as a base for simulation models. As stated by Kendrick (12), simulation models are mostly input-output and ... "they are built around the use of linear technology in the form of the Leontief input-output matrix." Analytical techniques have been developed for economic analysis of an input-output model with stochastic parameters for technology coefficients, and the demand vector (18), and it is felt that combined systems modeling and time series analysis would be extremely advantageous (36).

A review of systems engineering approaches thought applicable to the current effort is given in a subsequent section. In addition, the problem of sector definition and aggregation was deferred to the next section.

3.3.2 Sector Definition and Aggregation

During the early stages of this research it was felt that the definition of the sectors and the associated aggregation (disaggregation) problem were of primary interest in order to have a working model. It was originally envisioned that the economic model would be hierarchically structured and that an input-output matrix model would be decomposable down through the organizational levels i.e., a input-output matrix at, for example, the strategic level, would be (or could be) structured such that subsets of the matrix would be identifiable at lower levels. To adequately approach this concept, it was felt important to have a proper definition of a sector and, in particular, have a definition that is readily beneficial to a computer terminal based user. The associated aggregation problem also had to be put into proper perspective so as to consider the feasibility of hierarchical matrix decomposition as originally envisioned.

In the preparation of input-output tables, a decision must be made as to the size of an input-output table. In its original usage at the national level, the number of sectors chosen where usually based on Census of Production and other national statistical classifications (35). As noted by Lofting (12), sectors considered were typically the agricultural sector, household sector, manufacturing sector, etc., and the term "sector" is also used to include government operations, foreign trade, and capital formation. In business, the basic unit is a firm and all firms producing similar goods or services would then constitute a sector (or industry). As implicitly noted in the discussion of Section 3.1.1, once the sectors are determined the transaction matrix is prepared. The transaction table is then converted to an input coefficient table which gives direct industry purchases per unit of output. Further conversion of the direct coefficients results in the Leontief inverse matrix which gives direct and indirect industry purchases necessary for a unit increase in industry output to the final purchasing sector.

From an analyst or decision-maker's viewpoint, it is important at times to reduce the number of individual industries to a more manageable number. The basic question that must be asked is: Can the producing industries (sectors) be aggregated? i.e. Can the sectors be cumulatively added together in representative sectors dependent on the uses of the table?

Aggregation is an extremely complex problem and the approach (method) one takes in aggregation can have an effect on the results obtained. Three frequently used criteria are: (a) substitutability, (b) complementarity, and (c) similarity of production functions. Substitutability considers aggregating products that are close substitutes for one another. The second criterion aggregates products that compliment on another and are used in relatively fixed proportions. Products having the same production process (i.e. production function) would be aggregated by the third criterion. Still, none of the criteria are foolproof in that it is almost impossible to meet the above criteria (20).

It should be noted in the previous paragraph that the term product is used instead of sector. This nomenclature results from the fact that Leontief considered the economy consisting of a number of interacting industries with each industry producing a single good by using only one production process to make this good. As such, each industry can be considered a production process producing one product and must produce enough to meet exogenous (external) demand.

If one considers the basic assumptions of input-output analysis (static, open model), there are typically three. These are as follows: (1) the economy can be divided into a finite number of sectors with each sector producing a homogeneous product, (2) there are neither external economics nor diseconomies in production, and (3) the level of output from a sector determines (uniquely) the quantity of each input which is purchased. In aggregation, it has been pointed out (16) that it is necessary to distinguish between micro sectors and macro sectors. Macro sectors are simply combinations of micro sectors. Micro sectors are assummed to obey the above assumptions whereas macro sectors do not.

Considering the thrust of this research to develop an economic activity ($IDEF_0$) model for the ICAM program, the preceding statements would obviously have an impact on the approach taken. From the factory-center-cell-process hierarchy of the ICAM program, and to be consistent with the organizational hierarchy as reviewed in Section 3.2.1, the factory level was considered synonymous with the organizational strategic level. In addition, the next lower level, i.e., the tactical level, would consist of the planning and scheduling done for a center. A center is defined as a combination of various cells, and naturally much consideration to coordination would have to be developed at this level. The operational level was taken as an individual cell containing various processes which are sequenced to produce a product and/or partial product. This delineation of the factory/center/(cell-process) to correspond the strategic/tactical/operational levels, respectively, is artificial in the sense that in an actual organization there would undoubtably be some overlap. Still, the classification aids in visualization of the hierarchy.

The top-down philosophy of the ICAM program would then be a disaggregation of sectors as one proceeds down the organizational layers. For example, if at the strategic level one would have a specific matrix with a specified number of sectors defined, each sector or some subset of sectors could be an aggregation of sectors arrived at from lower levels. Such macro sectors would be the converse of a bottom-up approach where one would start at the operational level with elemental (indivisible) micro sectors. It would seem, from the point of view of this researcher, after considering the development of input-output models, that the bottom-up approach would be more easily implementable in practice. It has been stated by Leontief himself (30, page 26)

> "...As the industrial breakdown becomes more detailed, however, engineering and technical information plays a more important part in determining the data. A perfectly good way to determine how much coke is needed to produce a ton of pig iron, in addition to dividing the output of the blast furnace industry into its input of coke, is to ask an ironmaster. In principle there is no reason why the input-output coefficients should not be entirely derived from "below," from engineering data on process design and operating practice...."

Nevertheless, it is not meant by the previous statements that a bottom-up approach should be endorsed. Rather, it is envisioned that if a particular decision-maker at a particular level of the organization wishes to use an input-output analysis, the constructs of the model should be automated such that analytical techniques serve as an aid in proper application of the model. Thus at a very low operational level (e.g. consideration of operations within a cell), it would seem very feasible to define an input-output matrix with a finite number of sectors and without having to be overly concerned with aggregation. As one would proceed up the hierarchy (e.g. consideration of the coordination of many cells forming a center), the formulation of input-output tables would consider aggregation. This could be as simple as combining parts from cell A with parts from cell B to define the aggregate sector entitled "parts."

Conversely, at a high level (e.g. strategic), the decision maker would want assurance that his or her choice of sectors would be compatible with existing theory of input-output models. The problem encountered could be not only that of aggregation but also of disaggregation i.e. for the sectors chosen, could the matrix size be further reduced by aggregation and are the sectors already chosen aggregates themselves?

The definition of a sector that is adopted in this report is that a sector will refer to a substructure that can be associated with one and only one source. The term source is a general term in that it can refer to documents, data, primary resources, etc. It is a general term which in itself can be partioned into distinct subsets. A sector is then the source that generates the intersectoral flows. As such, every source defines a separate sector. With this definition, the input-output model of this research was extended to include graph theoretic (flow model) concepts. A separate sector can be assigned to each source and each intersector transaction will involve quantities related to manipulating and controlling the intersectional flow. For example a source input can be money (financial sector), number of parts produced (product sector), number of tons of coke required (a primary resource sector), etc. The conclusion of a graph theoretic approach as an adjunct to the activity input-output model is considered a valuable extension in that it "opens the door" to a large number of documented analytical techniques and illustrates the correspondence between matrix and graph theoretic approaches. This should give a more flexible system to a computer assisted user in IDSS.

It should be noted that the current effort is concerned only with an activity model ($IDEF_0$ methodology) that functionally describe an input-output econometric model. A full description would involve an information flow model ($IDEF_1$ methodology) which is outside the bounds of the current research effort.

In essence, the information flow model should be sufficient to enable sector definition and proper input-output matrix formulation for an extended Leontief input-output econometric model. Graph theoretic capability should serve as a valuable aid in model structuring and restructuring (through feedback capability) and in addition give flexibility to handle nonlinear problems. Also, it is not believed at the present time that the econometric model developed is all encompassing, but rather segment orientated and user definable. Thus, a user would percieve only a segment of the overall system and define his or her problem with a specific point of view. There would be sufficient built-in "safeguards" via the analytical techniques to aid in the proper construction and utilization of an econometric model. Such techniques would include sector definition and aggregation.

Leontief (30) notes that classification of industries for input-output analysis is guided by consideration of technical homogeneity and that the reduction of the size of an input-output matrix by consolidating (combining) some of its columns and corresponding rows gives rise to the problem of aggregation. Once an input-output matrix is formed, most applications require solutions of large systems of linear equations. Such solutions can be obtained by techniques computationally similar to large linear programming problems. Leontief noted that the extraordinary amount of computational effort provided the impetus to rearrange the rows and columns of the US economy to minimize computational requirements for numerical solutions. Such rearrangement brought into sharper focus the structural aspects of the economy.

Four basic concepts of structural analysis were stated by Leontief (30). These consist of dependence, independence, hierarchy, and circularity. Of interest to this research is the effect of these concepts on the formulation of the input-output table. These concepts or internal structures are revealed by an input-output table by the occurence of interindustry transactions. A completely interdependent economy would have its input-output table completely filled i.e. every cell representing an interindustry transaction would have corresponding numerical value. Of interest to this research was the triangulation of an input-output table which reveals a hierarchical pattern of interindustry transactions.

A hierarchical structure results in a triangular matrix such that the filled cells are below a diagonal running from the upper left corner to the lower right corner of the matrix. With such an ordering, sectors above and below a specified horizontal row corresponding to a given sector have different relationships with the given sector. As stated by Leontief (30, p. 48),

> "...Those (sectors) below are suppliers; any increase in final demand for its product generates indirect demands that cascade down the diagnol slope of the matrix and leave the sectors above uneffected. The sectors above, however, are its customers; an increase in final demand for the output of any one of them generates indirect demand for the output of the sector in question....computing the indirect effects of an increase in final demand for the output of this (specified) sector of demand originating elsewhere... work only with the input coefficients for this sector and the sectors above it...."

Due to the nature of the ICAM program with its "top-down" structured approach, it would seem natural that triangular matrices indicative of existing hierarchies would be predominant. Although it is not part of the current effort to structure an information ($IDEF_1$) model, it would seem reasonable to assume that the sectors defined as sources of information would be decomposable and compatible with ICAM activity models such that an alignment with triangular matrix theory would be naturally imposed by the methodology. Analytical techniques dealing with decomposition and triangulation thought of importance to the ICAM program are presented in the next section.

Previously it was stated that at a low operational level the formulation of a input-output model would be simplified by easier sector definition. Difficulties in formulation would arise from the aggregation problems that would exist at higher levels in the organizational structure. In both cases, a aggregation or simplification problem could be faced. The aggregation problem would occur whenever it is found that data is too numerous or in so much detail it cannot be effectively managed. The need to somehow group the data will then exist. The following short literature review is intended to present some of the concepts and existing analytical techniques which have been applied to this problem. The review is not all inclusive but hopefully gives insight into future beneficial research areas.

Ara (2) discussed the aggregation problem in input-output analysis and stated a necessary and sufficient condition for acceptable sector aggregation for a static input-output model in general equilibrium and autonomous final demand with homogeneous input structures. In addition, the dynamic stability condition and its relationship to aggregation was examined for a dynamic input-output system which was indecomposable, i.e., the matrix of technical coefficients ($\tilde{A}$) cannot be decomposed.

Gerking (16) notes that analysts are generally forced to aggregate sectors (specifically, microsectors) due to the unavailability of data or cost considerations. The macrosector analogues constructed by combining microsectors do not in general give identical results. He notes that aggregation bias can exist and presents techniques to account for such bias. His work pertained to a static, open input-output model. Also noted was the fact that aggregation bias was not the only source of bias in an input-output forcast, but that estimator error also occurs.

Perhaps the best reference text found on aggregation and its effect on economic modeling is the work by Fisher (13). A few points in the text are worth mentioning due to their possible implication on an economic model for the ICAM program. Fisher notes a need for simplification or aggregation. A chapter in his text is devoted to the simplification problem in input-output analysis. The approach is briefly outlined in the following paragraphs for a static, open, Leontief input-output model.

Fisher's approach differs from most approaches to the aggregation problem of input-output analysis in that it is an optimizing approach and the viewpoint is from micro-prediction error theory. Such an approach deals with micro-bias in the detailed forecasts after using an aggregation-disaggregation sequence, as opposed to determining bias in aggregated forecasts after aggregation alone.

If one considers a batch, X, of detailed data as a finite vector or matrix of real numbers which in itself is a element of a set of possible batches, then another batch, $\tilde{X}$, of simplified data is derivable from the detailed data by some procedure. This procedure or simplification function, f, can be represented as

$$X \xrightarrow{f} \tilde{X}.$$

An aggregation-disaggregation sequence is defined when $\tilde{X}$ has the same number of elements as X, and, in addition, there is a batch (reduced) of aggregated data $\bar{X}$ and relationship functions between X and $\bar{X}$ and $\bar{X}$ and $\tilde{X}$, respectively, i.e.,

$$X \xrightarrow{g} \bar{X}, \qquad \bar{X} \xrightarrow{h} \tilde{X}$$

The composite function, gh, is defined as the aggregation-disaggregation sequence. The composite function, gh, is also the simplification function, f.

Fisher notes that the simplification function has two essential aspects and a possible third aspect. The two essential aspects are the degree of simplification required and the method of weighting i.e., the weighting of the costs of the loss of information against the cost of detail. The third aspect is selection of a partioned disaggregation by cluster analysis techniques. Overall, the problem is to select a simplification function, f, which may be subject to any prior restrictions, such that the cost is minimized. The cost is taken as a function of the product set $(X,\tilde{X})$ and is assumed to consider the decision-maker's utility, effect of information loss for detailed subsets of observed data, and the cost of managing and handling detailed data as opposed to aggregate data.

In an input-output model, an optimal aggregation partition is sought with a corresponding row-column aggregation. As such, the partitioning applies both over the row and column indices of the coefficient matrix and its Leontief inverse, $(1\text{-}A)^{-1}$. Fisher presents a detailed procedure for partioning which he terms the "lockstep" progressive merger procedure. He also presents a chapter on clustering methods which he believes useful in solving aggregation problems in econometrics.

This section of this report has had as its intent to present an interpretation of sector definition that can be used in the economic model for the ICAM program. The intent was also to acknowledge the existence of analytical techniques believed important if and when an economic model is implemented. As a point of future research, a need has been established to build information flow models which, in essence, would serve as inputs to the activity model of this report.

3.3.3 Comments on Systems Engineering Approaches

System engineering approaches have as their basis the mathematical theory of graphs. This section is intended to give a brief review of systems engineering approaches to the Leontief input-output model and its corresponding matrix formulations and solution techniques. As such, the review is descriptive and is not intended to be all inclusive. As before, the intent was to make the reader aware of the existence of analytical techniques that could possibly be applied to the structure of the econometric input-output model of the current effort. Naturally, further research would have to be done once specific information structures are determined for the input-output functional model.

Various authors have considered linear programming approaches to input-output models. For a competitive economy, Haimes (21) presented a linear program with the objective to maximize the value of final demand which can be satisfied in an input-output economy with resource or factor input limits. One form of this linear program is as follows:

$$\max \quad Y_F = \tilde{1}^t \, (I-A) \, \tilde{X}$$

subject to

$$W \tilde{X} \leq \tilde{h}$$

$$\tilde{X}, \tilde{Y} \geq 0$$

where Y_F - final demand value, $\tilde{X}$ = vector of gross outputs for sectors j, (j = 1, ..., n), A = n x n matrix of production (technical) coefficients, W = m x n matrix of resource use coefficients, and $\tilde{h}$ is a vector of m resource availabilities. Haimes text is focused on water resource systems and particularly, hierarchical analyses of such systems. In addition to the above linear programming model, he presents extensions which incorporates a concave piecewise linear objective function. One model also presented is a multilevel approach to a supply-demand model coordination. Although too detailed to examine here, the model is interesting from the ICAM viewpoint in that analytical techniques are presented which correlates general regional economic activity and resource availability. The model also considers dynamic effects caused by discounting future costs and benefits. The author notes that the multilevel coordination approach has computational advantages over a totally integrated supply-demand model, and with supply and demand components defined separately the model is more flexible. The separability of the supply scheduling model from the input-output demand mode at the lowest level enables substitution of sub-models. For example, a static economic model could be replaced by a dynamic Leontief model or discrete scheduling models could be replaced by continuous cost curves. It is at the next highest level (management planning level) that the supply and demand models are coordinated. Numerous texts and articles exist on multilevel systems theory as referenced in earlier sections of this report.

As noted by Hadley (20), a graph theory representation of a Leontief model reveals several interesting features of a Leontief economy. Hadley states examples for both decomposable and indecomposable economies. An indecomposable economy exists if each industry (sector) buys directly or indirectly from all other industries; otherwise the economy is decomposable. If an economy is decomposable, then the technology matrix for m separate economies (where each of the n economies can contain a finite number of sectors) can be written as

$$\tilde{A} = \begin{bmatrix} \tilde{A}_1 & \tilde{0} & \dots & \tilde{0} \\ \tilde{0} & \tilde{A}_2 & \dots & \tilde{0} \\ \vdots & & & \vdots \\ \tilde{0} & \tilde{0} & & \tilde{A}_m \end{bmatrix}$$

As noted in the previous section, it would seem plausible that an economic model for the ICAM program would impose a technology matrix with a triangular form, i.e.

$$\tilde{A} = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1k} \\ \tilde{0} & A_{22} & \cdots & \tilde{A}_{2k} \\ \vdots & & & \vdots \\ \tilde{0} & & & \tilde{A}_{kk} \end{bmatrix}$$

With such a form the economy is decomposable, but not completely decomposable. The standard interpretation of the triangular matrix as given above is that every industry (sector) is in a group K. Industries within a specific group K buy directly or indirectly from other industries within the group. Sales are to industries outside a group K only occur to industries in groups with an index greater than K. As noted by Hadley, the industries (sectors) must be numbered properly for the matrix $\tilde{A}$ to have the triangular form. With the matrix formed, various authors have presented techniques to arrive at solutions for large scale problems with partioned submatrices. Hadley also discusses the closed Leontief model, the case for alternative activities, and dynamic Leontief models. He notes that there are many ways of obtaining dynamic Leontief-type models and presents one method of converting a deterministic, dynamic Leontief model to a form requiring a linear programming problem solution at each step.

One other early reference on linear programming applications to input-output analysis is the text by Gass (15). He presents a different linear programming form than previously mentioned in that the approach was to maximize profit for a

Leontief model. In brief, he considers the following linear programming problem

$$\max \quad \tilde{c}\,\tilde{X}$$

subject to:

$$(\tilde{I}-\tilde{A})\,\tilde{X} + \tilde{W} = \tilde{Y} - \tilde{S}_o$$
$$\tilde{X} + \tilde{U} = \tilde{L}$$
$$\tilde{X} \geq \tilde{0}$$

where $\tilde{X}$ is a production vector, $(\tilde{I}-\tilde{A})$ the Leontief matrix, $\tilde{Y}$ is the predicted final demand vector, W is a vector of non-negative slack variable, $\tilde{S}_o$ is a vector representing the stock of various items from previous production, $\tilde{U}$ is a vector representing the unused capacity of each industry, and $\tilde{L}$ is a vector denoting the known capacity levels for each industry.

The system as described is a static Leontief model since it considers an economy over a single time period. Gass also considered a linear programming formulation of a similar but dynamic model in which he accounted for expansion of the capacity level of each industry to meet future period final demands. With his model, he was able to arrange a tableau of coefficients which had a block-triangular form. He notes the computation complexity of block-triangular configurations and cites a need (for that time) for further work. To the best of this researcher's knowledge, many classes of structured problems have been identified and algorithms developed for their solution since the publication of the Dantzig-Wolfe decomposition principal published in 1960.

Sage (37) notes that input-output models can be interpreted with block diagram techniques which are familiar to systems engineers. He presents the basic input-output model of Leontief and several modifications. These modifications included what he termed externalities (external effects) which include not only outputs resulting from the activity of production which may have helpful or harmful effects on the industry itself producing the output but also other industries and society at-large. These externalities can include various types of pollution, taxes, etc. He presents the matrix equations and the associated block diagrams for various static input-output models and a dynamic input-output model.

In addition, Sage notes various important studies which can be accomplished with input-output analysis. Such studies could use input-output analysis to compute shifts in price structure resulting from externalities, to measure environmental, social, and economic impacts not only of alternative production technologies, but also various substitutions among industry total output rates, or alternative resource inputs. He notes that the dynamic input-output model may be used to describe dynamic transitions in production states in response to changes in demand.

As stated previously, one extension to the input-output model which was felt valuable was to provide a graph-theoretic modeling capability. From an $IDEF_0$ modeling viewpoint this would mean the inclusion of an additional activity. It was felt that graphical approaches would have a more intuitive appeal to an analyst and would aid in the construction of large scale input-output matrices. In addition, it would provide a better transition to the simulation models being developed within the ICAM program. In essence, it was believed that a graphical counterpart to the input-output matrix approach could easily be modified or restructured to be amenable to simulation techniques. It is not the intent of the current effort to completely review graph theoretic modeling. From a structured modeling viewpoint, the reader is referred to the tutorial guide by Lendaris (28). Rather, the intent here is to briefly note flowgraph analysis as a graphic modeling technique to be used in conjunction with the output matrix model.

As stated in Whitehouse's text (43), a flowgraph is a graphical representation of the relationships among variables and simultaneously displays all relationships among the variables of a given system. A flowgraph consists of sets of nodes and branches (termed transmittances) with the nodes representing variables and branches indicating relationships between the nodes they connect.

Whitehouse presents two models of economic systems as a demonstration of the effectiveness of flowgraph analysis. One model of a simplified corporate economy consisted of nodes (sources) labeled, for example, as new capital investment, total research funds, etc., and branches defining the parameters of the system e.g., income from research, return on manufactured products, etc. With a flowgraph model, interactions among various corporate activities can be determined. In addition, questions relating to economic sensitivity and stability can be evaluated.

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IV A Hierarchical Input-Output Econometric Model for Production Systems

The literature review of Chapter III was directed to defining the activities that would be necessary to perform an input-output economic analysis. In addition, extensions to a basic input-output model were researched and analytical techniques thought relevant to such an extended input-output econometric model were reviewed. The present chapter is directed toward synthesizing such knowledge obtained from the literature into a workable generic and functional model. Counterpoint to the body of knowledge from the literature is the economic model development currently existing within the ICAM Decision Support System (IDSS) program. Such model development was also considered in the development of the IDSS input-output econometric model presented in this chapter and Appendix A.

The point of view taken in this research was to establish the structure for a generic econometric input-output model within the specifications of the $IDEF_0$ methodology. As a guide to the feasibility of such a model, the approach taken was to abstract the necessary minimal structure that describes a manufacturing system and use this structure as a basis for the input-output econometric model. The manufacturing system structure obtained was of a form similar to the ICAM composite view of aerospace manufacturing. The objective of relating the ICAM composite view to the manufacturing system structure was to identify which nodes (or family of nodes) in the ICAM composite view of aerospace manufacturing were at the strategic, tactical, or operational levels as commonly referred to in the literature.

4.1 Production Systems Structure and IDSS Economic Models

4.1.1 Relationship of ICAM Composite View to Organizational Levels

As noted previously (Section 3.2), a management system can be viewed both hierarchically and functionally. To arrive at a general structure to identify the activities at the strategic, tactical and operational levels, a nodal diagram is based primarily on the text by Hitomi (Section 3.2, ref. 22). The diagram is a result of individual student and group efforts resulting from a first year graduate course taught by this researcher at the University of Rhode Island during the fall semester of 1980. The purpose of the effort was to illustrate a hierarchy for a firm as commonly detailed in the literature. The point-of-view taken was that of industrial engineers. As a result of these efforts the following nodal diagram was obtained:

- A0 Plan and Implement Production
  - A1 Establish Business Goals
    - A11 Establish Philosophy of the Firm
    - A12 Evaluate System Environment

- A13 Decide Management Policies and Objectives
- A2 Do Strategic Planning
  - A21 Clarify Management Strategies
  - A22 Organize Personnel
  - A23 Plan Investment for facilities/plant
  - A24 Plan Sales Strategy
  - A25 Do Financial Analysis
  - A26 Evaluate Production Plans/Performance
- A3 Do Tactical Planning
  - A31 Acquire Forecasts
  - A32 Plan Aggregate Production
    - A321 Plan Resources
    - A322 Do Process Planning
      - A3221 Design Process
        - A32211 Analyze Work Flow
        - A32212 Select Work Stations
      - A3222 Design Operations
        - A32221 Analyze Man-Machine Systems
        - A32222 Analyze Human Factors
        - A32223 Standardize Production Operations
        - A32224 Select Optimum Processes
      - A3223 Do Layout Planning
        - A32231 Select Alternative Layouts

A32232 Do Systematic Layout Planning

A33 Plan Sales

A34 Design Products

A341 Establish Product Specifications

A342 Do Product R&D

A343 Make Parts Description of Products

A35 Develop Production Schedules

A36 Develop Production Controls

A4 Implement Production

A41 Procure Resources

A42 Produce Products

A421 Control Production Orders

A422 Control Production Items and Tools

A423 Perform Physical Production

A424 Test and Deliver Products

A43 Maintain Inventory

A431 Establish Raw-Materials Inventory

A432 Establish Work-in-Progress Inventory

A433 Establish Finished Product Inventory

A44 Control System Operations

A441 Control Manpower

A442 Control Product Quality

A443 Control Production

As can be noted from the nodal diagram, the objective was to differentiate the activities within the strategic, tactical, and operational levels of a manufacturing firm. Much more detail could be illustrated for the nodal diagram. As noted previously for an integrated production management system (refer: Table 3.3), the Logestic system has the function to implement the production planning which is accomplished at the tactical (management) level. In essence the logistics system comprises the operation level denoted by node A4-Implement Production.

The ICAM Composite View of Aerospace Manufacturing nodal diagram is given in reference 1 at the end of this section. With the aid of the developed nodal diagram, identification of ICAM Composite View nodes with strategic tactical and operational (logestic) levels was facilitated. It should be noted that the Composite View (CV) model was developed by a coalition of all major aerospace companies and represents a syntheses of actual Factory View (FV) operations. As such, the effort here is restricted in that it was done independently of the coalition. Still, it is hoped that the effort will at least make a small contribution to the program and provide impetus for further efforts.

The ICAM Composite View has as its context the A-0 node, Manufacture Product. The following Composite View (CV), nodes are identified as belonging to the tactical or operationsl levels:

<u>Tactical Level</u>: CV/A1 - Plan for Manufacture
CV/A2 - Make & Administer Schedule & Budgets
CV/A3 - Plan Production

<u>Operational Level</u>: CV/A4 - Provide Production Resources
CV/A5 - Obtain Manufacturing Materials
CV/A6 - Produce Product

The existing ICAM Composite View has as its context (A-0 node): Manufacture Product. As such, tactical and operational nodes were readily identifiable. With the current CV nodal diagram, strategic level nodes are not readily identifiable. From a functionally hierarchical viewpoint, the CV/A-0 node is in itself one of four activities which comprise the CV/A-1 node: Develop and Produce Aerospace Product. The CV/A-1 node is one of four activities which comprise the CV/A-2 node: Get and Use Aerospace Product. For the nodal diagram developed as part of this research (A0: Plan and Implement Production), the strategic level would be associated with the A1 and A2 nodes (A1: Establish Business Goals; A2: Do Strategic Planning).

Considering Tables 3.2 and 3.3, previously presented on this report the viewpoint taken was that the strategic planning would deal with functions that establish objectives ar licies and supervise tactical and operational levels and encompass senior and middle management personnel. As such, composite view nodes CV/A-21 and CV/A-11 are readily identifiable at the strategic level (CV/A-21: Plan to Accomplish Objectives; CV/A-11: Manage Product). Since these nodes represent activities associated with the CV/A-2 and CV/A-1 nodes, they would draw on the data from all other activities and be linked through the composite by the information flow.

Considering that the thrust of this research is the development of an economic model, it seems feasible that the information flow linkages would aid in defining and clarifying an input-output model. For example, if one considers the operational level node CV/A6 (Produce Product), one could move vertically down the hierarchy to obtain more and more detailed information as needed. Such information could include cost models, parts requirements, etc., from very low levels in the hierarchy (e.g. Do Simple Brake Forming) which could also be aggregated horozontally across nodes at a specific level of the hierarchy. Horozontal movement across the hierarchy for the CV/A-0 nodal diagram would then include tactical and operational levels and their interfaces. For a given information model, it would seem possible that an input-output table could be constructed. If the information is properly defined and/or analytical techniques (e.g. cluster analysis) exist to aid the decision-maker, then input-output table formulation should be attainable. Such input-output tables could be formulated within the constructs of a vertical Composite

View decomposition or horozontally across nodes. Within the ICAM Decision Support System, it would seem possible to have a model that would be responsive to an individual decision-maker and his or her needs, and, furthermore, an input-output table could be constructed specific to the individual's needs. It is suggested that this approach be more fully developed by additional research.

4.1.2 ICAM Decision Support System Economic Models

The ICAM Decision Support System (IDSS) program has generated a considerable amount of information (2,3,4,5, 6,7,8,9). As noted by Austell, et. al. (4), IDSS supports the design and analysis of systems which, in general, have certain generic characteristics consisting of procedural operations, parallel processing, shared resources, operational loading, and process communication. IDSS, in earlier stages of the contract, identified manufacturing needs and presented possible solutions and known available software to support the solution of such needs (2,3). Various analytical technique function models have since been developed following the $IDEF_0$ methodology (5,6). Concurrent with this research performed at the University of Rhode Island on input-output econometric modeling has been the effort at Higher Order Software (HOS), Inc. at Cambridge, MA. The effort at HOS is still ongoing and most recently has considered problems of economic analysis in IDSS and the implications for the IDSS System (9).

Earlier work on economics within the IDSS program have resulted in development of econometric and engineering economic models (3,5,6). Nodal diagrams and associated $IDEF_0$ functional model were developed for the following contexts: (1) Perform Engineering Economic Analysis, (2) Perform Econometic Analysis. In addition, an $IDEF_0$ model of construction procedures for a preliminary economics model (entitled: Construct Economics Model) has been presented (5). This latter model was interesting in that it attempted to approach an economic model via multi-level hierarchical systems theory as discussed in Section 3.1.1. Following discussions with HOS Inc. personnel 41-11 on such an approach, it was felt that the multi-level hierarchical systems theory approach did not satisfy immediate needs of the IDSS program.

Economic modeling approaches to IDSS (to the best of the author's knowledge at this point in time) have primarily consisted of the aforementioned working $IDEF_0$ models or to literature reviews pertaining to the context of economics within IDSS (9). This latter review by HOS which was done concurrently with this research report presented a broad overview of the economic tools considered relevant to IDSS. Compared to the literature review of this report, it was much broader in its approach although input-output analysis, activity analysis, and systems descriptions and economics comprised subsections of the report. Interestingly enough, many of the problems discussed in the HOS report served to counterpoint identical problems discussed in this report.

One goal of the HOS report was "to discuss the relative value of multiple interacting economic models as opposed to a single economic model for IDSS." As such, it was considered possibly more appropriate to take advantage of "intercommunicating or interacting economic models, a possibility that is technologically feasible given IDSS resources." In essence, as can be noted throughout the literature review of this report, the opinion of this author is similar. The input-output model which was originally considered was extended to incorporate additional features (static versus dynamic, flow graph capability, econometric techniques, etc.) to give a user a higher degree of modeling flexibility. The model developed as a result of this research is discussed in the next section and presented in Appendix A.

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4.2 An Input-Output Econometric Model for IDSS

The primary objective of this research effort was to construct an activity ($IDEF_0$) model following a specific modeling procedure as detailed in the ICAM program. In con-junction with the effort was a rather substantial (but not completely exhaustive) literature review. The review was undertaken to determine the feasibility of the model and to identify existing analytical techniques to be used in conjunction with the model. The $IDEF_0$ model developed was entitled "Do Input-Output Econometric Analyses" and is presented in Appendix A. Since the model as presented in Appendix A incorporates a text and glossary which is sufficient for definition of the model, this current section is intended as a general overview of the model.

The hierarchical breakdown detailing the activity of each node for "Do Input-Output Econometric Analyses" is as follows:

- AØ: Do Input-Output Econometric Analyses
  - A1: Formulate Transaction Table & Input-Output Model
    - A11: Access Economic Flow & Physical System Data
      - A121: Determine Input Sectors
      - A122: Determine Demand Sectors
      - A123: Aggregate Sectors
      - A124: Distinquish Primary & Intermedate Inputs

A13: Formulate Transaction Table

A131: Form Interindustry Flow Matrix (Quadrant I)

A132: Form Production Output-Final Demand Matrix (Quadrant II)

A133: Form Primary Inputs-Production Sectors Matrix (Quadrant III)

A134: Form Primary Inputs-Final Demand Matrix (Quadrant IV)

A135: Organize Transaction Table

A14: Calculate Input-Output Coefficients

A141: Calculate Technical Coefficients for Interindustry Flows

A142: Calculate Technical Coefficients for Primary Inputs-Production Sectors

A143: Calculate Interdependence Coefficients

A2: Formulate Flowgraph Model

A21: Identify Nodes

A211: Transfer Sectors to Nodes

A212: Determine Necessary Additional Nodes

A213: Formulate Complete Node Diagram

A22: Calculate Transmittance Functions Between Adjacent Nodes

A23: Verify Transmittance Functions Internally

A3: Do Static & Dynamic Analyses

A31: Do Static Analyses

A311: Do Input-Output Analysis

A312: Do Flowgraph Analysis

A313: Compare & Review Models

A314: Perform Econometric Analysis

A32: Do Dynamic Analyses

A4: Validate & Revise Models

From the nodal breakdown, it can be seen that initial activities involve the formulation of a transaction table and input-output model. It is envisioned that a User in conjunction with an analyst (if needed) would initially access the economic flow and physical system data and arrive at a manageble data subset considered to be important in the formulation of a transaction table and associated input-output model. With the data subset, specific input and demand sectors could be defined, and depending on problem definition, refined via aggregation techniques. Such refinement would aid in "sizing" the transaction table.

The approach taken as a result of this research was to incorporate (adjoin) flowgraph theory and analysis with classical input-output analyses. Thus, in conjunction with the initial transaction table and input-output model formulation,a flowgraph model is formulated. Pertinent to the structure of the overall model is the equivalence of the nodes of a flowgraph model to the sectors of a transaction table. By definition, a sector is a distinct source of information relevent to the problem description. Thus, a sector refers to a substructure of the data which can be associated with one and only one source. The term is to be interpreted such that any data subsets of a major data set can be considered as independent sectors, or, in combination, as one major sector. For example, a production line supplied by outside suppliers of ten different types of parts could be considered as ten different primary sources of input, or, upon combination, as one primary input labled number of parts from outside suppliers. Note that with such an example, one loses the detail of the number of individual types of parts. In fact, implicit with such a statement is that the different parts are additive-an assumption which may or may not be true. This problem of aggregation of sectors (or conversely, disaggregation), as discussed in the previous chapter, is approached primarily via cluster analysis techniques and/or by specified criteria (complementary, etc.).

It should also be noted that a feedback loop consisting of a node diagram exists between the A1 and A2 activities. The node diagram resulting from the formulation of a flowgraph model aids (via graphical techniques) the user in any necessary restructuring of the transaction table and the associated input-output model.

Once the flowgraph model and input-output model are formulated, analysis for both the static and dynamic cases are performed. Static analysis is time independent and dynamic analysis is time dependent and typically multi-period. The static analyses gives as output classical statistical econometric models and an imput-output model.

From the dynamic analyses, optimal dynamic system models are obtained. These models consist of a dynamic (multi-period) input-output model and a dynamic production system model with nonlinear capability. Feedback loops exist to update model coefficients.

For the A-0 diagram of the model, four general analytical techniques are identified. These consist of statical techniques, flowgraph and simulation techniques, mathematical techniques, and math programming techniques. In the model presented in appendix A, the techniques are labeled AT/ST (analytical technique/statistical techniques), AT/FST (.../flowgraph and simulation techniques, AT/MT (.../mathematical techniques), and AT/MPT (.../math programming). The following list is compiled to give a more specific explanation of the analytical techniques though useful for incorporation in the model:

Node	Analytical Technique	Explanation
A123	AT/ST	Cluster analysis is the statistical technique considered as a viable technique
	AT/MT	Mathematical techniques dealing with concepts such as additivity, partitioning, complementariness, etc.
A141	AT/MT	Simple algebraic or matrix manipulations
A143	AT/MT	Algebraic or matrix manipulations i.e., interdependence coefficients are coefficients of Leontief inverse matrix, $(\tilde{I}-\tilde{A})^{-1}$.

A311	AT/MPT	Linear programming, integer programming, or mixed integer/linear programming.
A312	AT/FST	Flowgraph techniques, e.g., Mason's rule, topological techniques, etc.
A314	AT/ST	Standard statistical techniques associated with classical econometric analysis such as multiple regression, goodness-of-fit tests, hypotheses tests, time series analysis, etc.
A32	AT/ST	Time series techniques; further investigation into combined time series/systems modeling approach considered useful.
	AT/MP	Dynamic programming could be used.
	AT/FST	Simulation techniques e.g. (It is anticipated that simulation techniques being developed within the ICAM program would be used.)

In the formulation of a transaction table, four separate submatrices for the table have been identified. These four matrices correspond to the four quadrants of the schematic layout given in Figure 3.3 for a transaction table in input-output analysis. Quadrant I defines the interindustry flow matrix. For the purposes of the current model, this quadrant describes the transactions internal to the firm or some aspect of the firm, e.g. a department, division, production line, cell, center, etc.. In Figure 3.3, this quadrant is labeled intermediate input to intermediate demand. Quadrant II identifies what transactions occur between the producing (internal) sectors and the demands placed upon the producing sectors. Quadrants III and IV are used to identify transactions between the primary inputs to the production sectors and between the primary inputs to final demand, respectively.

With the above general structure for the transaction table, the input-output model can be formulated. Dependent on problem definition and associated sector definition, matrices can be partitioned to exhibit substructures (e.g. environmental pollution, waste disposal, value added effects, etc.). Solution techniques as discussed in Chapter 3 can then be applied to such structured input-output models.

V. Summary and Conclusions

An input-output econometric model was constructed for the Integrated Computer Aided Manufacturing (ICAM) program of the US Air Force. The model generated was an activity model and was constructed in accordance with $IDEF_0$ methodology. A literature review was accomplished to aid in the of the model and to identify various existing analytical techniques which can be applied to the model.

In general, the model was a combined model consisting of a classical input-output model, flowgraph theory, and classical econometric models (i.e., those econometric procedures distinct from input-output analysis). The necessity of considering the information flow for the model was discussed and documented. Both the static analysis and dynamic analysis cases were incorporated in the model. Major outputs of the model consist of a transaction table, transmittance functions, econometric models, an input-output model, and optimal dynamic system models. The latter model outputs result in a dynamic (multi-Period) input-output model and a production system model.

Specific general conclusions that can be drawn from this stage of the research are as follows:

1. The input-output econometric model as constructed and defined exhibits the flexibility and feasibility necessary for use in an interactive decision support system.

2. Various analytical techniques have been identified which would aid in any future implementation of the model.
3. Sector definition by a user and/or analyst was aided with incorporation of feedback from flowgraph analysis of a graphical node diagram. Such computer-based graphical techniques are of value in restructuring of the input-output model generated.
4. Flowgraph analysis gives a non-linear capability to the overall modeling construction in conjunction with linear input-output models.
5. Dynamic (multi-period) models can be considered within the context of the overall model presented.

VI. Recommendations For Future Research

As a result of the literature review and the research performed, various topics were arrived at that would be beneficial for future research. Considering the contents of this report, future research topics of interest could be of a theoretical nature or of a more practical, methodological approach. Among the various topics, the following list of recommendations are considered of more immediate interest:

1. A corresponding information model should be constructed using $IDEF_1$ techniques which would serve as a possible aid in further refinement of the activity ($IDEF_0$) model of this report.
2. The aggregation problem as defined in the text of this report is of crucial concern. Further investigation is needed into cluster analysis techniques or other techniques (e.g. partioning) to aid in sector (node) indentification and sizing of the transaction table generated.
3. Specific case examples should be investigated to verify the applicability of the model.
4. The model as presented identified various analytical techniques. These techniques should be matched to the techniques which have already been developed in the ICAM program. Possibly, extensions to existing analytical techniques can be developed or new models

generated for non-documented analytical techniques within the program.

5. More theoretical work needs to be done on the general topic. Of immediate interest would be matrix decomposition techniques and their relationship to flowgraph analysis in a hierarchical setting.

The above recommendations are but a few that could be made. Also of interest would be further development of the multi-level approaches as reviewed in this report. It is hoped that this report with its associated review has aided to define problems of interest that are beneficial to US Air Force.

Appendix A

This appendix consists of a model entitled "Do Input-Output Econometric Analysis". The model has been generated following $IDEF_0$ methodology.

ST 252

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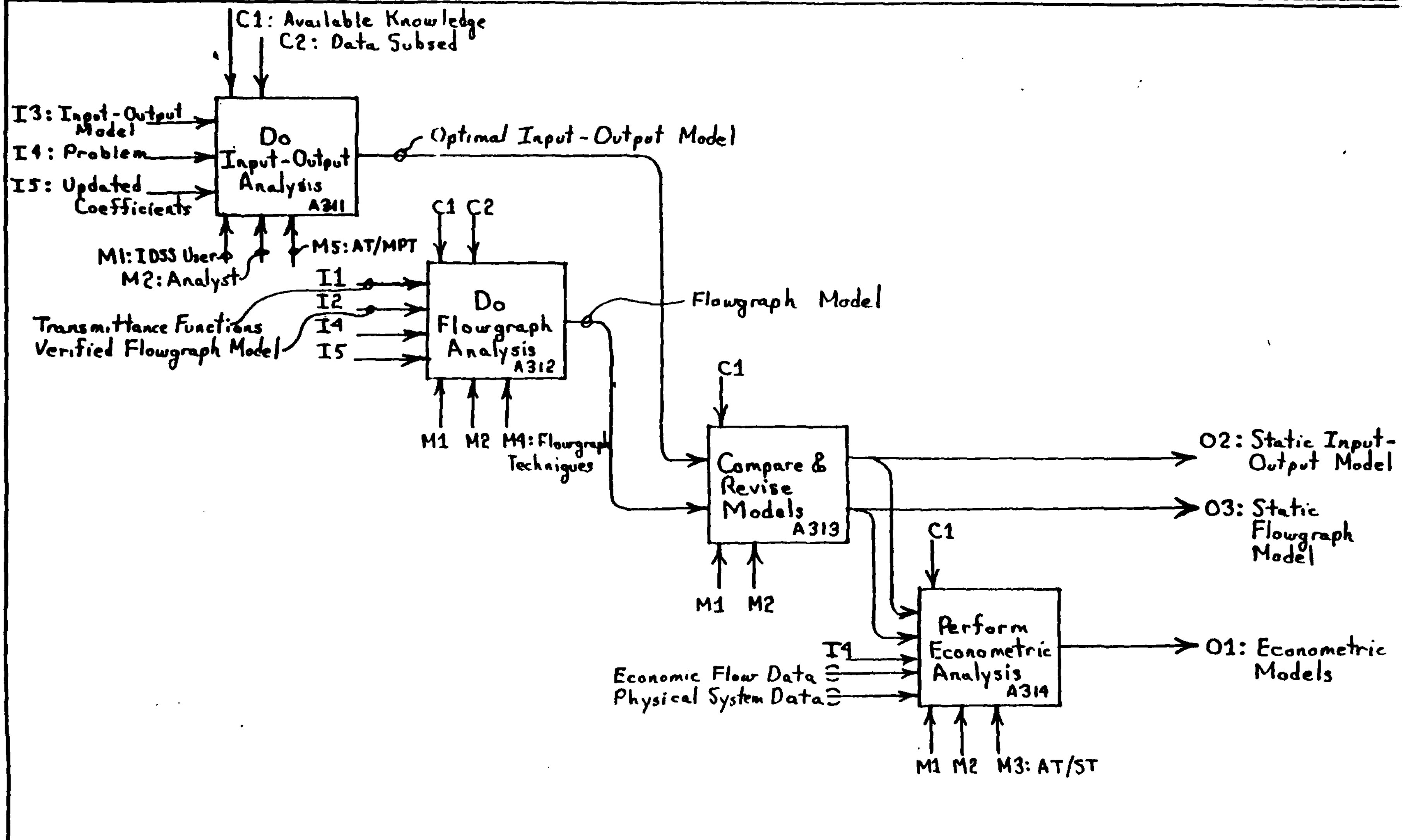

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ST 252

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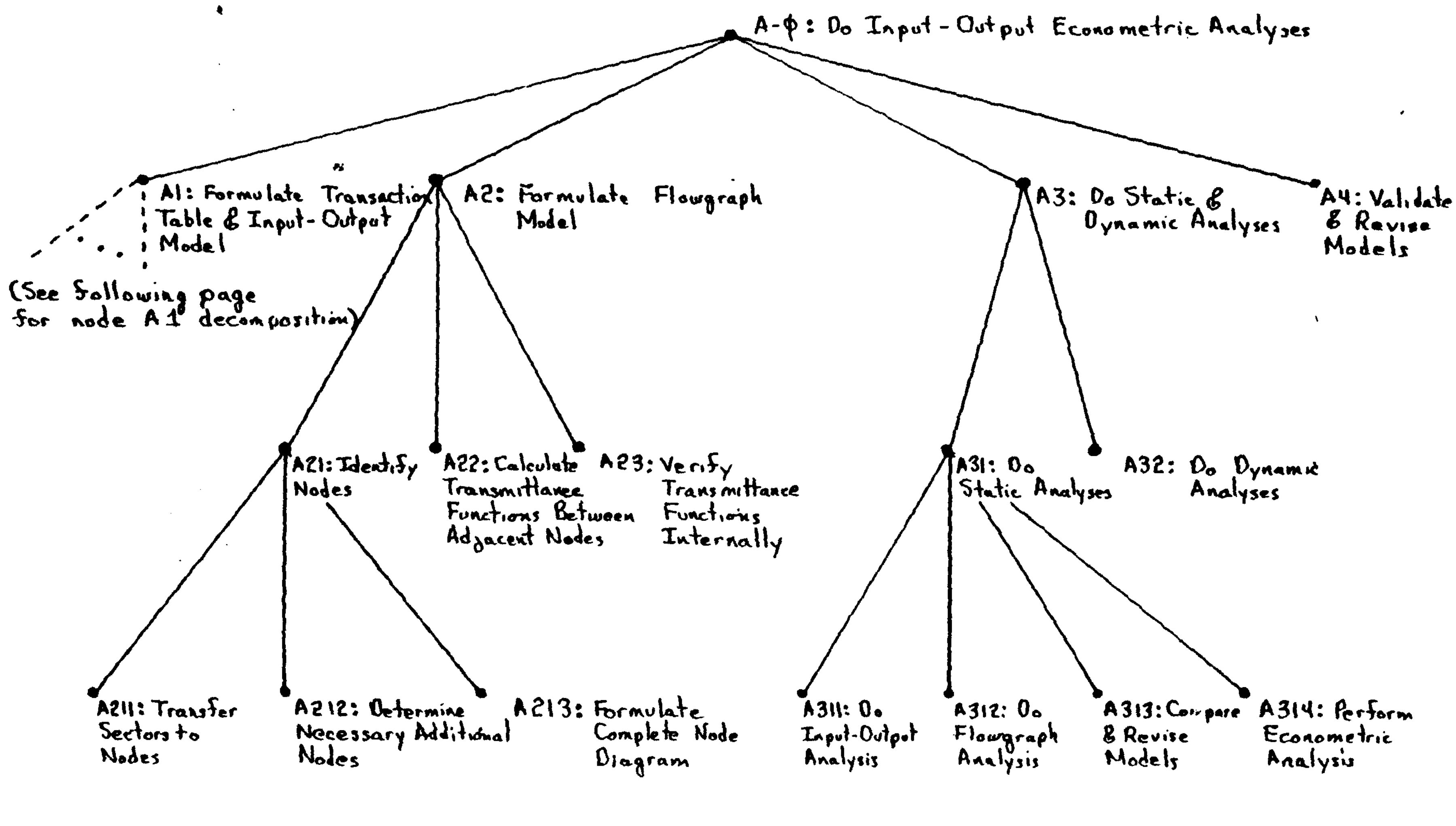

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ST 252

USED AT:

AUTHOR: N.G. Odrey
PROJECT: AFOSR-80-0123

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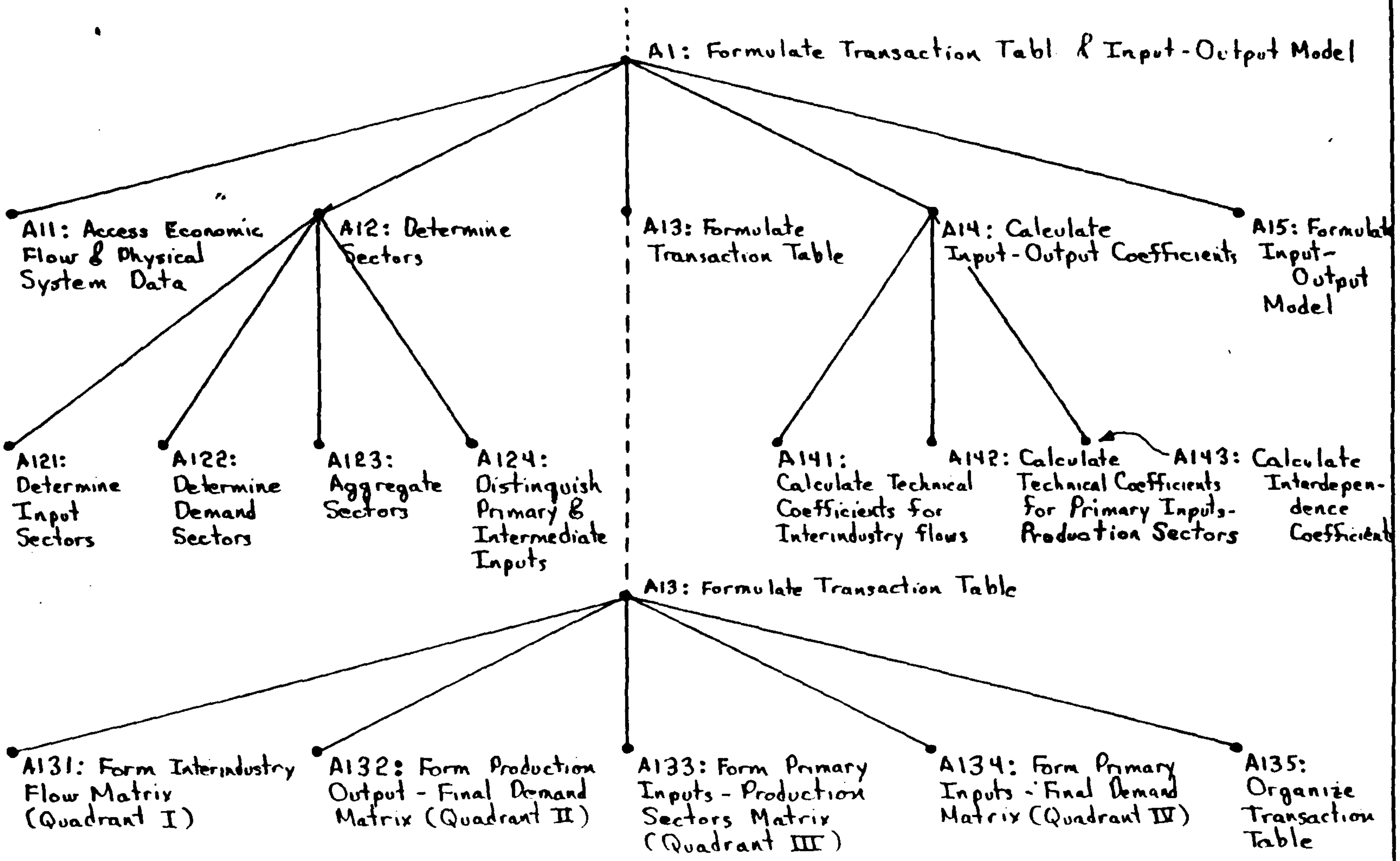

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ST252

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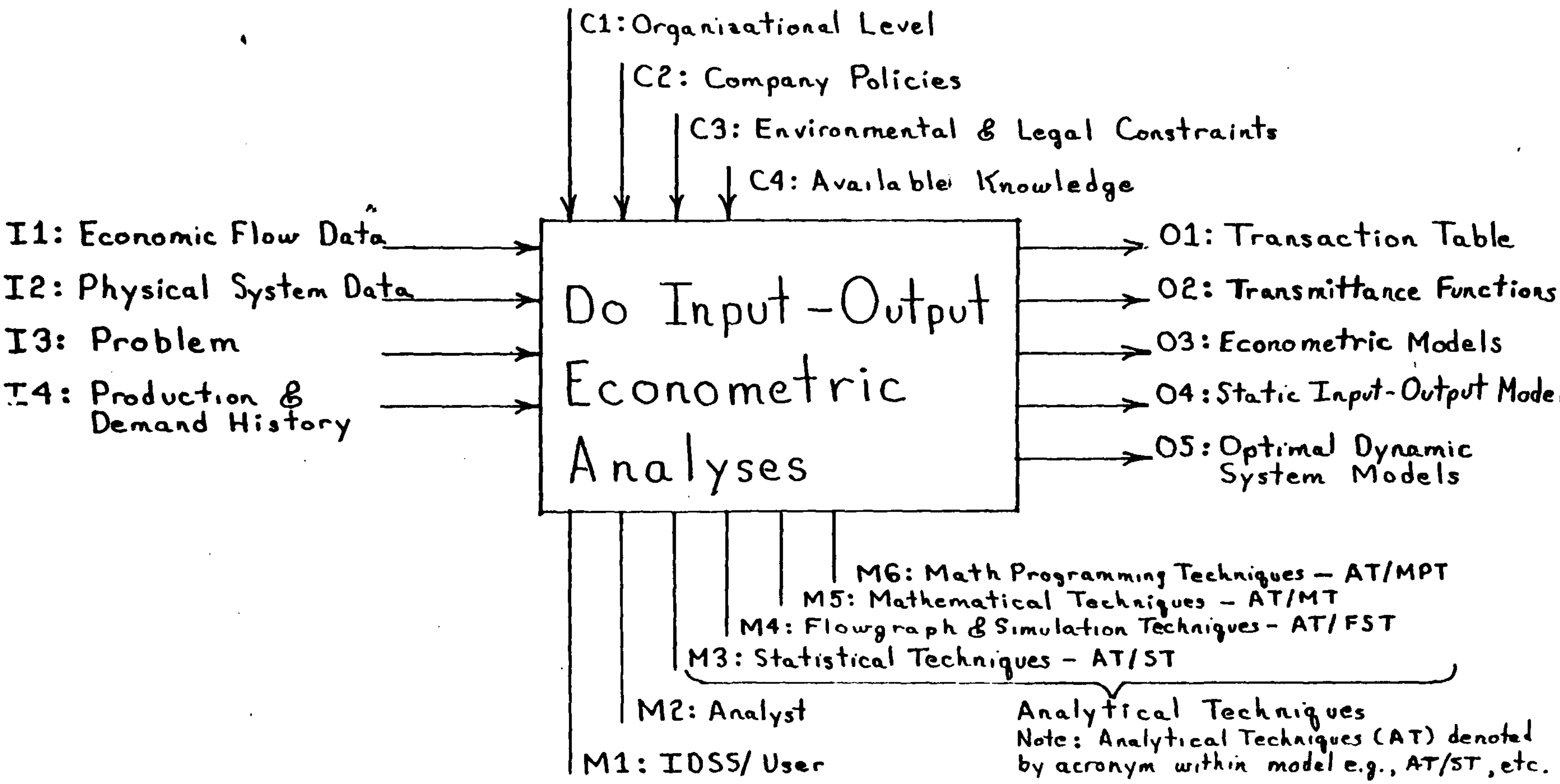

Purpose : To Describe an Input-Output Econometric Model for the ICAM Decision Support System (IDSS)

Viewpoint: Industrial Engineer

NODE: A-O	TITLE: Do Input-Output Econometric Analyses	NUMBER: NGO-1

ST252

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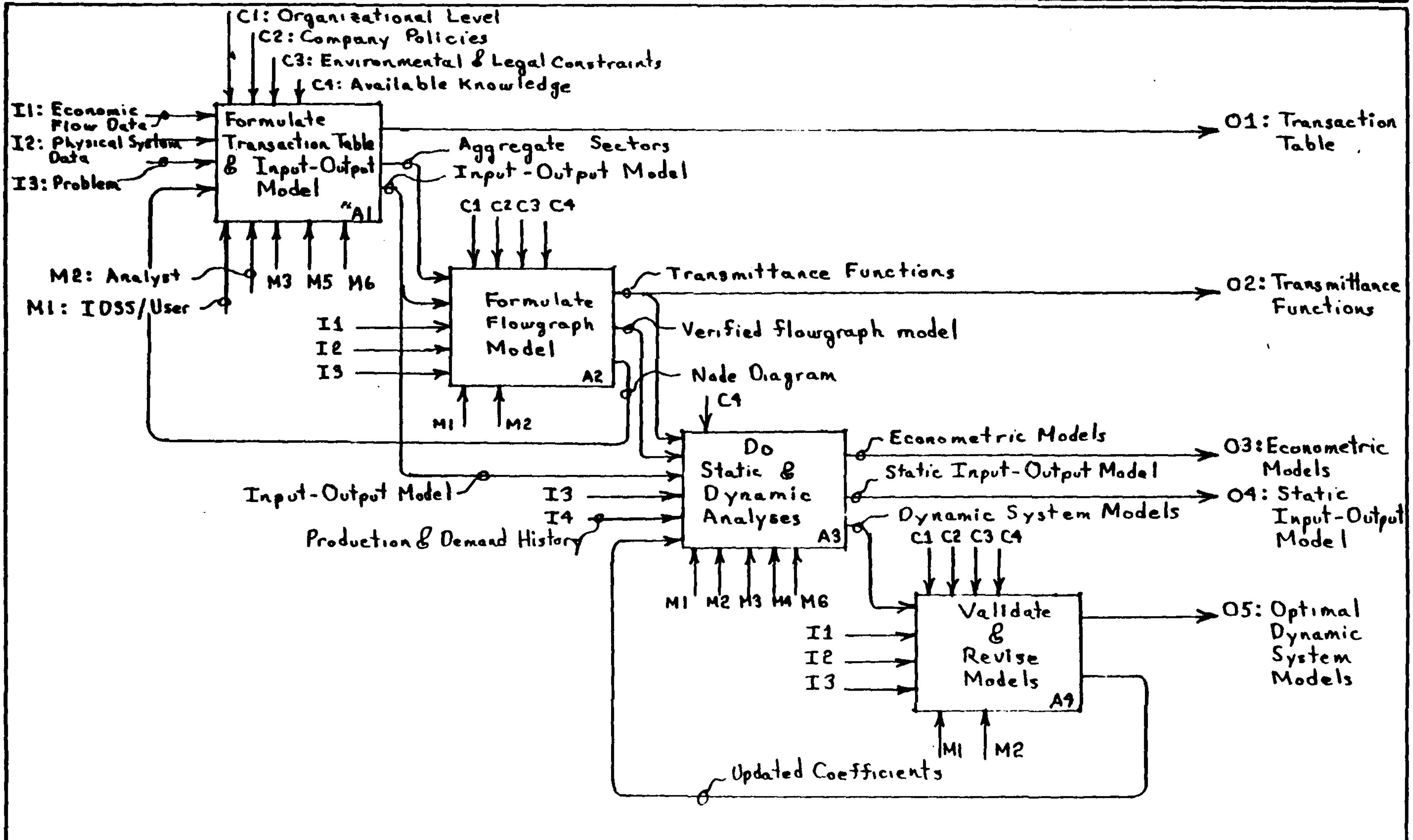

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ST252

USED AT:	AUTHOR: N.G. Odrey PROJECT: AFOSR-80-0123 NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 6/30/81 REV:	WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT:

Text for A0

Formulation of the Transaction Table involves accessing the economic flow and physical system data and forming a data subset tentatively identified as important to the problem definition. In addition, existing relationships which relate economic flow data and physical flow data are accessed (e.g. production functions). Following aggregation for sector definition, initial matrices are formed and input-output coefficients are calculated. Concurrently or as a second step, a flowgraph model is formulated. The flowgraph model aids (via graphical techniques) the user in restructuring, if necessary, the transaction table. An input-output model and a verified flowgraph model are formed and serve as input to econometric analyses. Analyses are performed for both the static and dynamic cases. Static analysis is time independent whereas dynamic analysis is time dependent and typically multiperiod. Following any required validation and revisions, the final output is a final production system model. Additional output consists of an input-output model and classical statistical econometric models.

Glossary for A0

Economic Flow Data	Economic data available to the user and/or analyst for the problem at hand. Can include accounting/cost/finance data, cost relationships, etc.
Physical System Data	Pertaining to the physical system of the organization or some subset of the organization e.g. raw material input, number of parts of a specific item, input-output relationships for physical data, etc.
Problem	Definition of what the analysis is attempting to do.
Available Knowledge	What is the available general and technical level of knowledge of the organization, who will use the analysis, and what is the state of the art in defining what the problem is.

NODE:	TITLE:	NUMBER:

Glossary for AO (cont'd)

Organizational Level	Those levels of the organization (whether strategic, tactical, or operational) which provide information for the problem at hand. This information bounds the context of the problem and aids in definition and structuring of the problem.
Transaction Table	A table consisting of an arrangement of the various sectors which describes the transactions between sectors for a stated period of time for a specified problem. The entries in the table thus describe the flow between all individual sectors. Also referred to as an Input-Output table.
Input-Output Model	A mathematical model consisting of a set of linear equations formulated from the Transaction Table, which describe the functional relationships between the individual sectors of a given system.
Transmittance Function	In flowgraph analysis, transmittance functions give the mathematical relationships between nodes for a system. A system consists of variables represented by nodes and the relationships that exist between the variables are represented by branches. The branches connecting the nodes are called transmittances.
Econometric Models	Statistical based economic model construction that frequently involves interrelated equations to study interaction within an economic system. Models other than the dynamic system models generated by this report.
Optimal Dynamic System Models	The outputs from doing dynamic analyses which results in a dynamic (multi-period) input-output model and a dynamic production system model with nonlinear capability.

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PROJECT: AFOSR-80-0123

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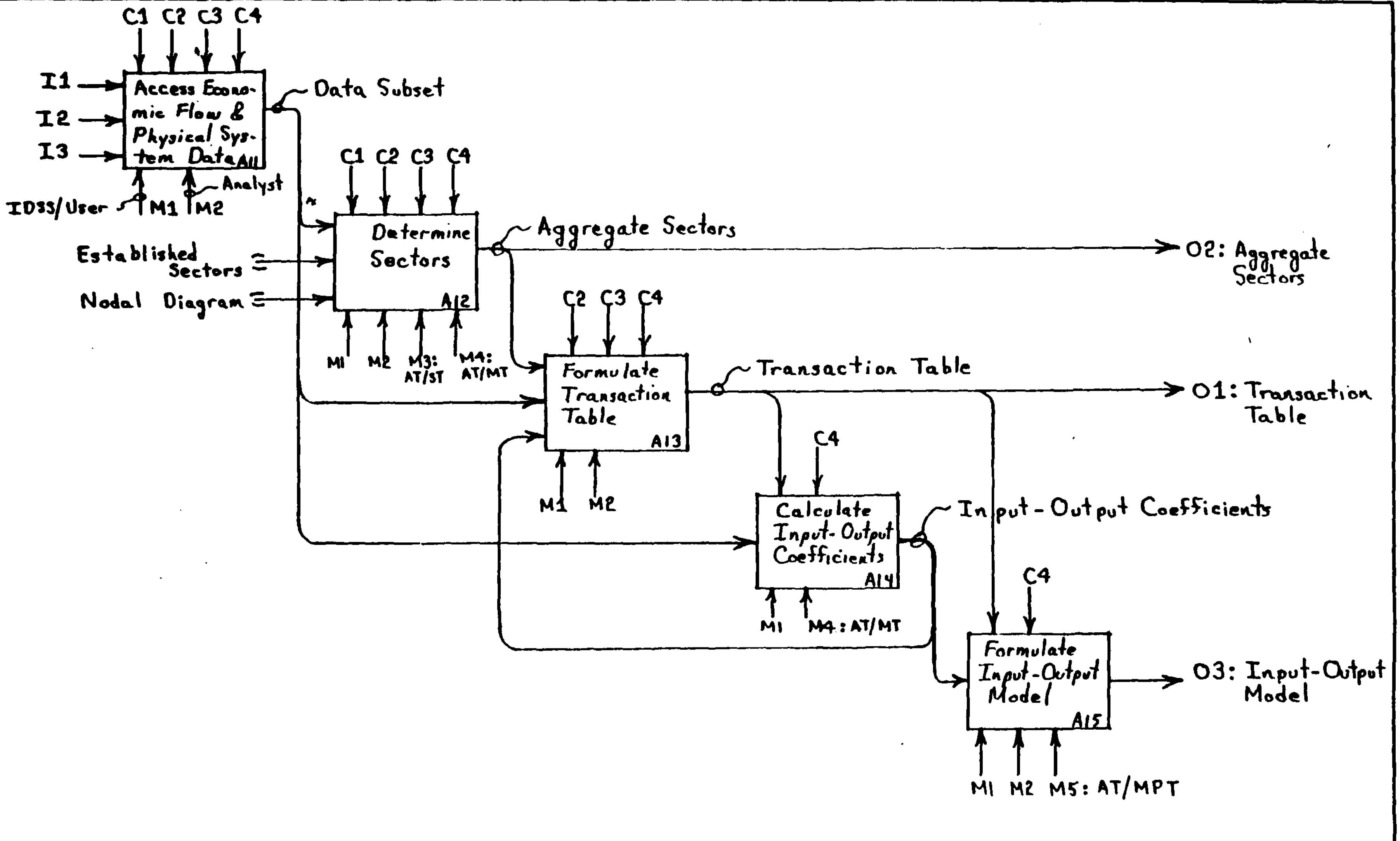

NODE: A1

TITLE: Formulate Transaction Table & Input-Output Model

NUMBER: NGO-3

ST252

USED AT:	AUTHOR: N. G. Odrey PROJECT: AFOSR-80-0123 NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 6/30/81 REV:	WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT:

Text for A1

The first step in formulating the transaction table and an input-output model is to access the economic flow data and physical system data for the defined problem. A user and/or analyst would then have a data subset from which to determine via analytical techniques (e.g., cluster analysis, etc.) the sectors for the formulation of the Transaction Table. The next steps are to formulate the transaction table and to calculate the input-output coefficients. The input-output coefficients serve to aid as feed back for any necessary restructuring of the transaction table. The final step is to formulate the system of linear equations which define an input-output model.

Glossary for A1

Sector	A distinct source of information relevant to the problem description. The information can be economic and/or physical system data (e.g. documents, primary resources, no. of parts, etc.). Refers to substructure of the data which can be associated with one and only one source.
Established Sector	Those sectors which are established by convention or policy.
Aggregated Sectors	Those sectors which have the capability to be aggregated into distinct new sectors via aggregation techniques (e.g., cluster analysis, etc.) or by specified criteria (e.g. complementary, etc.).
Input-Output Coefficients	The sets of coefficients necessary for construction of an input-output model consist of technical coefficients and interdependence coefficients.
Data Subset	The subset of economic flow data and physical system data considered by the user and/or analyst to be important in formulating a Transaction table and associated input-output model.

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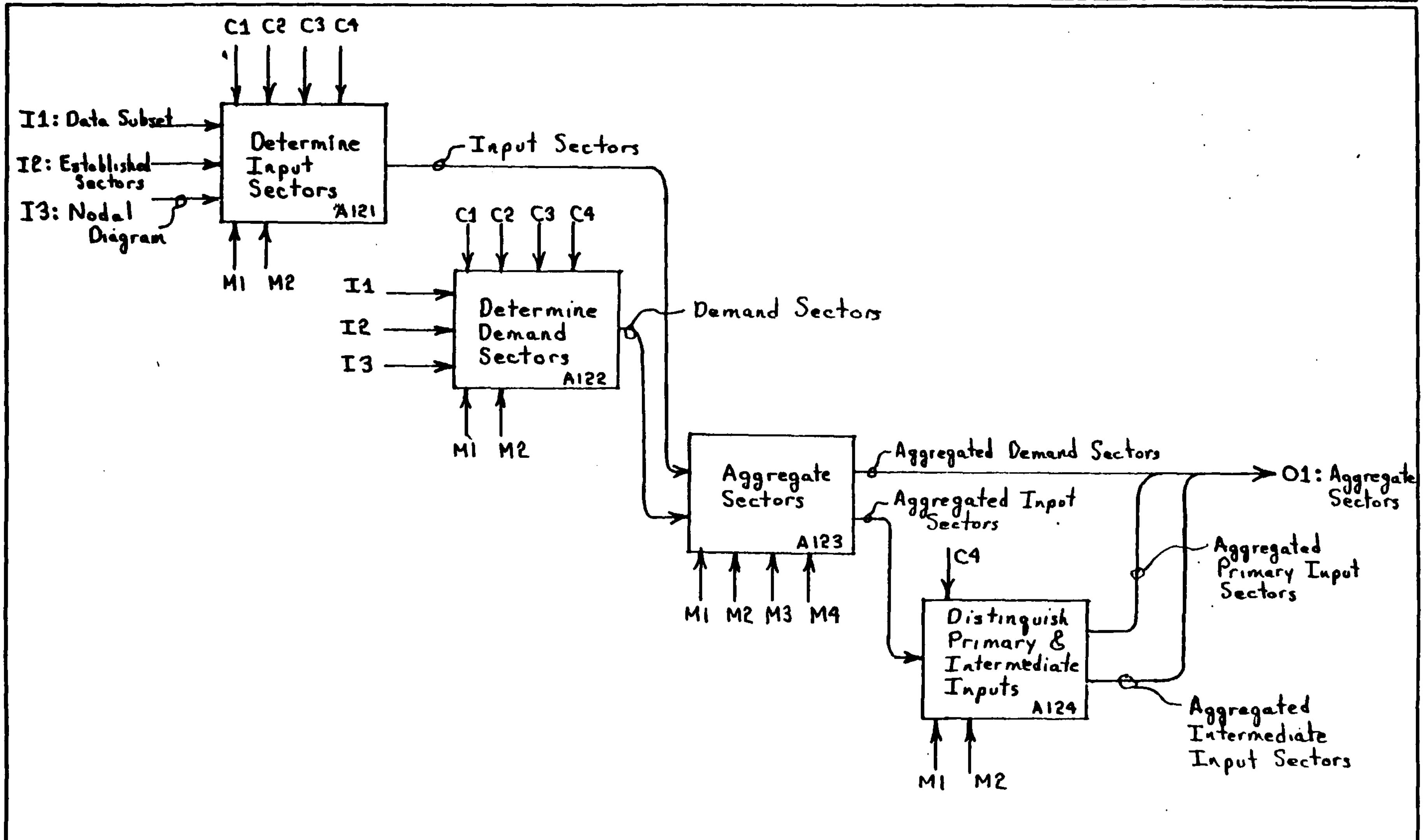
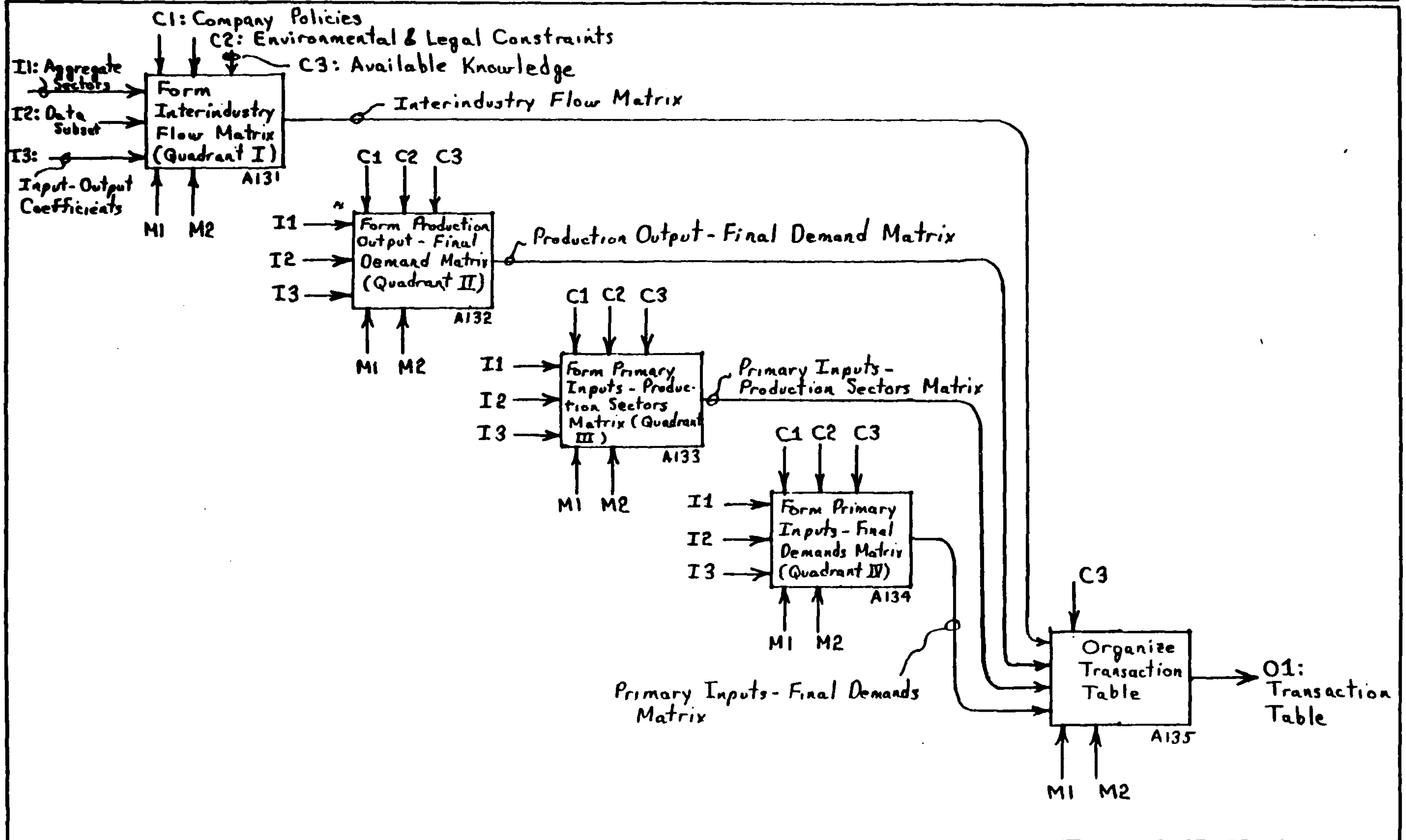


NODE: A12	TITLE: Determine Sectors	NUMBER: NGO-4

ST252

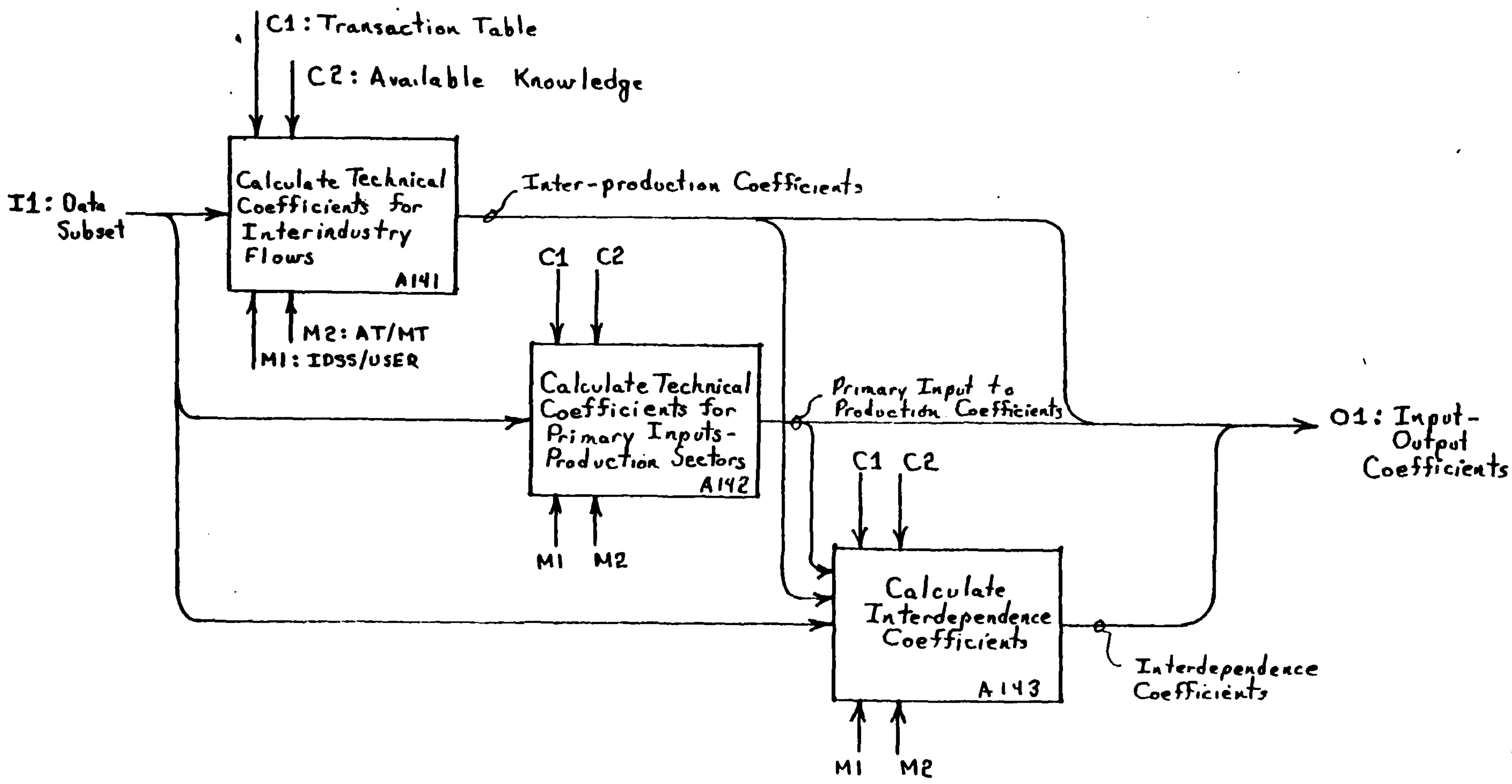
USED AT:	AUTHOR: N. G. Odrey PROJECT: AFOSR-80-0123 NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 6/30/81 REV:	☒ WORKING ☐ DRAFT ☐ RECOMMENDED ☐ PUBLICATION	READER DATE	CONTEXT: A1



NODE: A13	TITLE: Formulate Transaction Table	NUMBER: NGO-5

ST252

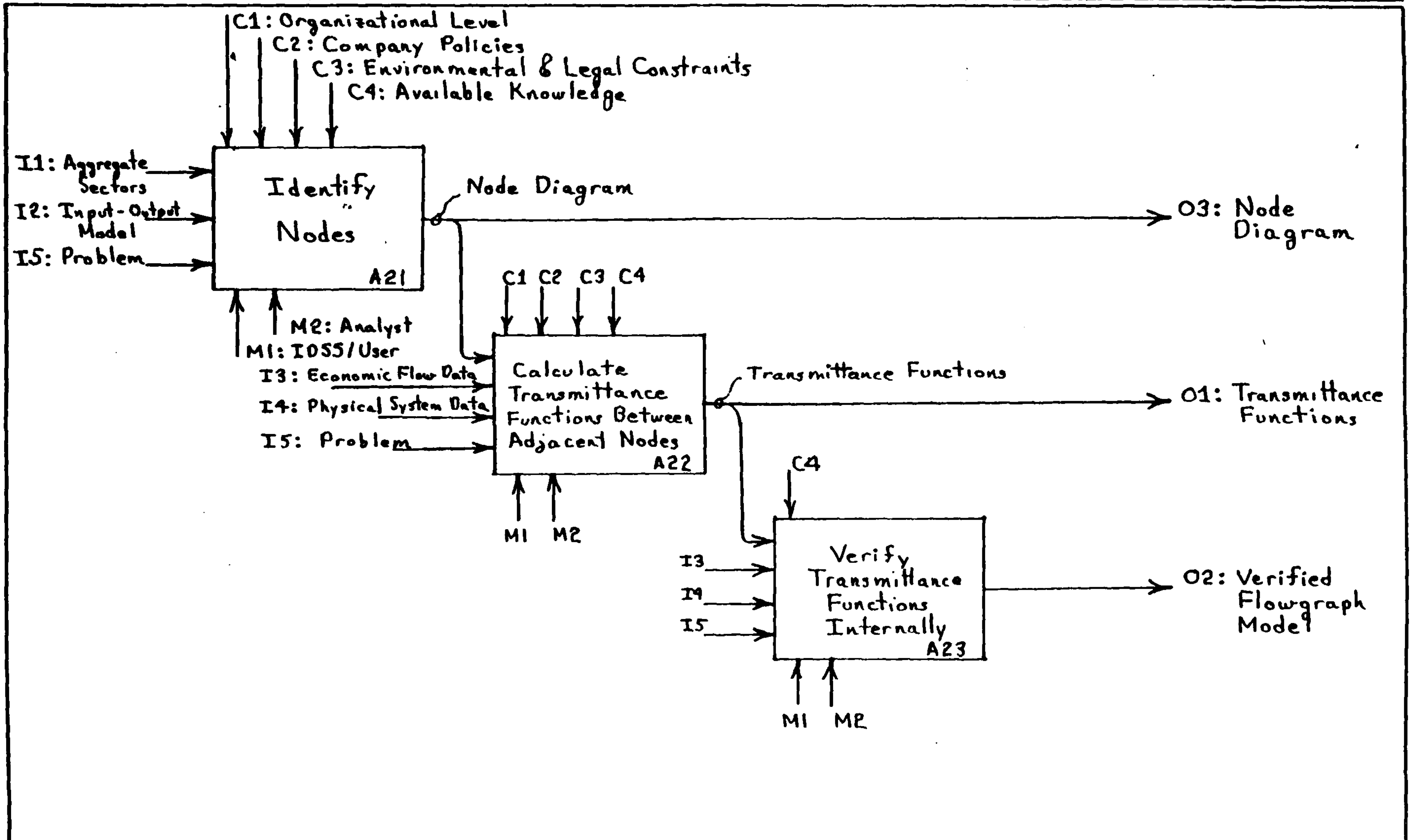
USED AT:	AUTHOR: N.G. Odrey PROJECT: AFOSR-80-0123 NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 6/30/81 REV:	X WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT: A1



NODE: A14	TITLE: Calculate Input-Output Coefficients	NUMBER: NGO-6

ST252

USED AT:	AUTHOR: N.G. Odrey PROJECT: AFOSR-80-0123 NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 6/30/81 REV:	X WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT: A0



NODE:	TITLE:	NUMBER:
A2	Formulate Flowgraph Model	NGO-7

ST252

USED AT:	AUTHOR: N. G. Odrey PROJECT: AFOSR-80-0123 NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 6/30/81 REV:	WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT:

Text for A2

To formulate a flow graph model, the initial step is to identify nodes. Nodes are identical to aggregate sectors as determined in the formulation of the transaction table (i.e. nodes are sources of information). Following the transfer of aggregate sectors to nodes, additional nodes are determined of necessary and a complete nodal diagram is formed. The node diagram serves as feedback to the transaction table formulation for refining or restructuring sector definition. With the node diagram (or visualization aids such as a matrix of nodes), transmittance functions are calculated between adjacent nodes. Following verification that the transmittance function between adjacent nodes (also includes transmittance (looping) of individual nodes) is a good match to the "real" world, a verified flowgraph model is outputted.

Glossary for A2

Node	Equivalent to the definition of a sector.
Node Diagram	A Pictorial Diagram of a set of nodes (sectors) and their directed connectivity.

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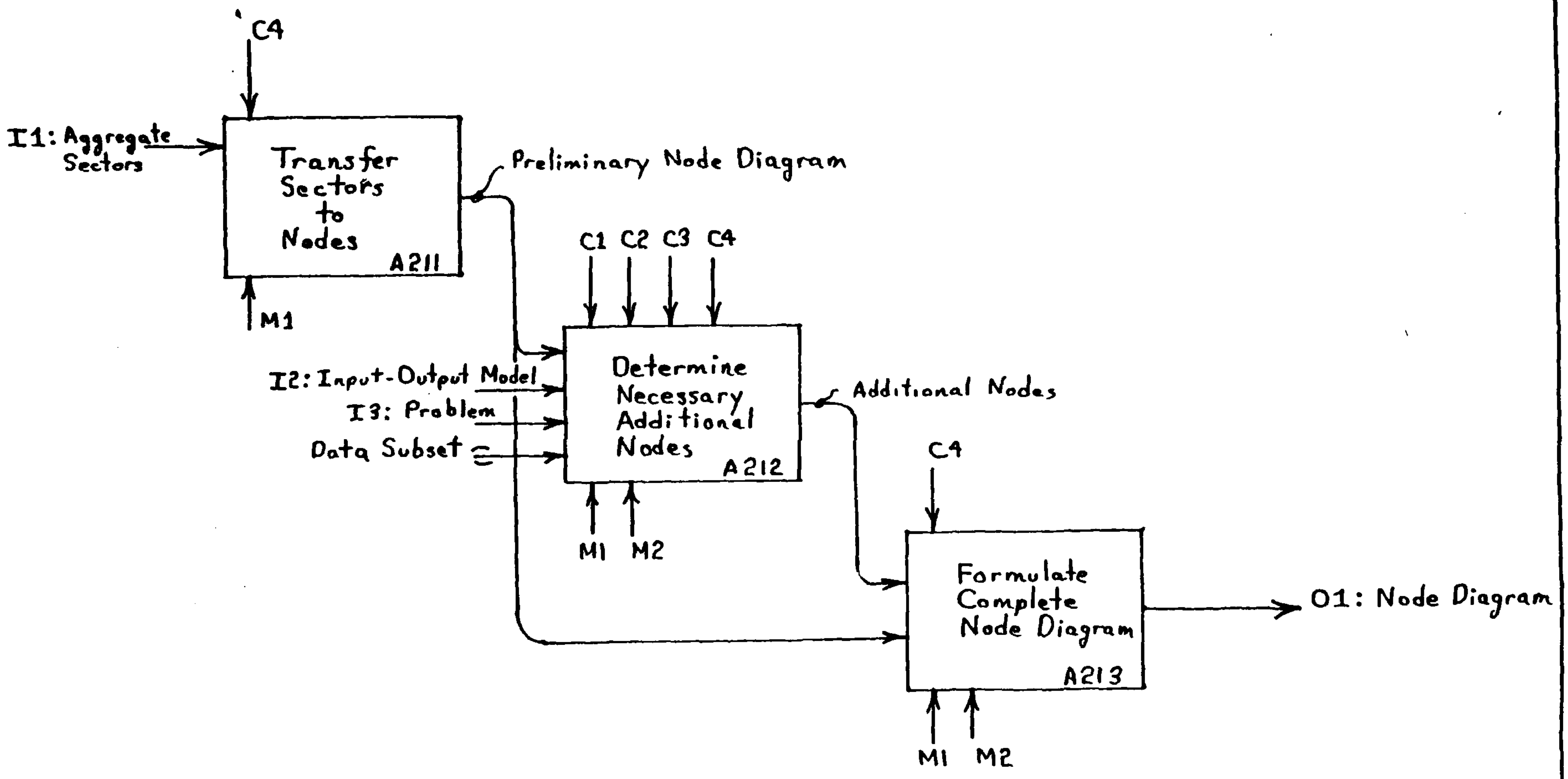
NODE:	TITLE:	NUMBER:

ST252

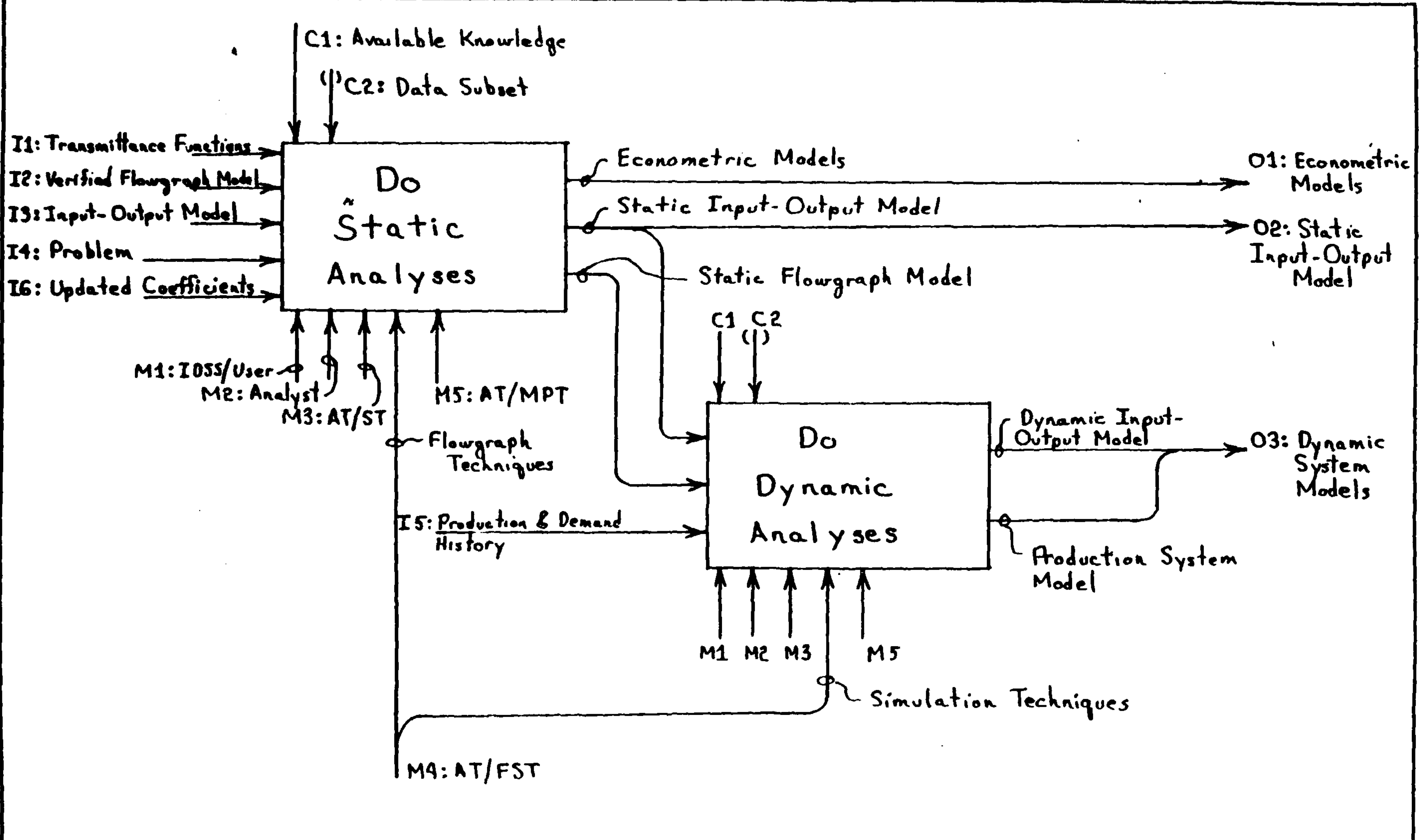
USED AT:	AUTHOR: N.G. Odrey PROJECT: AFOSR-80-0123 NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 6/30/81 REV:	X WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT: A2



NODE: A21	TITLE: Identify Nodes	NUMBER: NGO-8

ST252

USED AT:	AUTHOR: N.G. Odrey PROJECT: AFOSR-80-0123 NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 6/30/81 REV:	☒ WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT: A0



NODE: A3	TITLE: Do Static & Dynamic Analyses	NUMBER: NGO-9

ST252

USED AT:	AUTHOR: N. G. Odrey PROJECT: AFOSR-80-0123 NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 6/30/81 REV:	WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT:

Text for A3

The static analysis consists of initially arriving at an input-output model consisting of a linear system of equations to which math programming techniques can be applied (e.g. linear programming, decomposition techniques, etc.). A flowgraph model is obtained by doing flowgraph analysis. Flowgraph analysis analytical techniques consist of topological techniques, Mason's rule, etc.. The flowgraph model is typically nonlinear and represents the functional relationships among all nodes. The optimal input-output model and flowgraph model are compared so as to mutually detect differences in functional relationships. Such comparisons can result in further revisions (e.g., functional relationship additions, deletions, modifications, etc.) to both models. The resulting revised models serve as input to aid in the development of classical econometric models as documented in the literature (re: A. Diedloff, Perform Econometric Analysis, ATPE A-A-O, Volume II: Baseline Function Models, Interim Report by High Order Software, Inc., Cambridge, MA, October 1978 to October 1979). Dynamic analysis is performed next to accommodate multi-period models. Based on the production and demand history, static input-output and flowgraph models for successive periods are respectively linked. The outputs are a dynamic (multi-period) input-output model and a dynamic production system model with nonlinear capability.

Glossary for A3

Production and Demand History	Economic flow data and physical system data over successive periods pertinent to the problem at hand.

NODE:	TITLE:	NUMBER: